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THE

STEAM ENGINE

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A CATECHISM

OF THE

STEAM ENGINE

IN ITS VARIOUS APPLICATIONS IN THE ARTS

TO WHICH IS NOW ADDED A CHAPTER ON

AIR AND GAS ENGINES

AND ANOTHER DEVOTED TO

USEFUL RULES, TABLES, AND MEMORANDA

BY

JOHN BOURNE, C.E.

AUTHOR OF 'A TREATISE ON THE STEAM ENGINE' 'A TREATISE ON THE SCREW
PROPELLER' 'EXAMPLES OF STEAM, AIR, AND GAS ENGINES'
'A HANDBOOK OF THE STEAM ENGINE' ETC.

NEW EDITION

MUCH ENLARGED AND MOSTLY REWRITTEN

ILLUSTRATED BY 212 WOODCUTS

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PREFACE.

THE present work is substantially a new one. Retaining only the best portions of previous editions, and those rectified in their indications so as to be representative of the best modern practice, the residue has been wholly re-written; and I have spared no pains to render this reproduction more worthy of the reputation the work has so long enjoyed. The size of the page has been increased to enable larger and more important woodcuts to be got in; and it will be found that the cuts, which are mostly new, are now nearly three times more numerous than formerly.

The preliminary discourse, explanatory of the scientific principles of the steam engine and other thermo-dynamic motors, has been rendered much more complete than before, and the modern doctrines of thermo-dynamics have been fully expounded. An historical account has been given of the birth and parentage of the steam engine, and of its various stages of growth up to the commanding stature it has now attained. Examples have been introduced of the most important engines and boilers of different classes which have recently been constructed, such as the compound pumping engine of Mr. Hawksley, the compound marine engines and boilers of Messrs. John Penn and Sons, of Messrs. R. Napier and Sons, of Messrs. John Elder and Co., of the torpedo-boat engines and boilers made by Messrs. Thorneycroft and Co., and of the compound locomotive of the London and North-Western Railway.

An entirely new chapter of ninety-five pages has been added on the subject of air and gas engines—a topic of wide and increasing interest, regarding which no popular compendium has yet appeared. In this exposition the scientific principles are explained which must underlie any successful introduction of those engines. Numerous engravings are given of the parts of the most remarkable gas engines, and the leading features of some hundreds of projects for superseding the steam engine by a new thermo-dynamic motor are briefly described, and their merits briefly appraised. Another chapter, of the nature of an appendix, has been added for the reception of such useful engineering data as the engineer requires to have constantly at hand in the prosecution of his professional duties, but which have no special application to any one of the preceding chapters more than to the rest. The design of this addition is to make the work more self-contained. In some parts I have been assisted by my pupils, Messrs. Thomae and Edwards.

Although in this reproduction I have been most unsparing in my excisions, the work has nevertheless increased considerably in bulk. This has happened mainly because there are now more things to be spoken about than formerly.

Mechanical engineering is an art so rapidly progressive that any work professing to act as a guide to its operations must not only be frequently amended in the details of its teaching, but must also at longer intervals be recast altogether. This is the second time that this necessary task of regeneration has been performed by me. In all human probability it will be the last; and what I have now done in the way of improvement has been done in the interest of posterity.

JOHN BOURNE.

College of Practical Engineering,
London: 1885.

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SCIENTIFIC PRINCIPLES
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CLASSIFICATION OF ENGINES.

Q. WHAT is meant by a vacuum?

A. A vacuum means an empty space; a space in which there is neither water nor air, nor any thing else that we know of.

Q. Wherein does a high-pressure differ from a low-pressure steam engine?

A. In a high-pressure engine the steam, after having pushed the piston to the end of the stroke, escapes into the atmosphere, and the impelling force is therefore that due to the difference between the pressure of the steam and the pressure of the atmosphere. In the condensing engine the steam, after having pressed the piston to the end of the stroke, passes into the condenser, in which a vacuum is maintained, and the impelling force is that due to the difference between the pressure of the steam above the piston, and the pressure of the vacuum beneath it, which is nothing; or, in other words, you have then the whole pressure of the steam urging the piston, consisting of the pressure shown by the safety-valve on the boiler, and the pressure of the atmosphere besides.

Q. In what way would you class the various kinds of condensing engines?

A. Into single-acting, rotative, and rotatory engines. Single-acting engines are usually made without a crank, such as the engines used for pumping water. Rotative engines are engines provided with a crank, by means of which a rotative motion is produced; and in this important class stand marine and mill engines, and all engines, indeed, in which the rectilinear motion of the piston is changed into a circular motion. In rotatory engines the steam acts at once in the production of circular motion, either upon a revolving piston or otherwise, but without the use of any intermediate mechanism, such as the crank, for deriving a circular from a rectilinear motion. Rotatory engines have not hitherto been very successful, so that only the single-acting, or pumping engine, and the double-acting, or rotative engine, can be said to be in actual use. For some purposes, such, for example, as forcing air into furnaces for smelting iron, double-acting engines are employed which are nevertheless unfurnished with a crank; but engines of this kind are not sufficiently numerous to justify their classification as a distinct species, and, in general, those engines may be considered to be single-acting by which no rotatory motion is imparted. Furthermore, rotative engines have been in some cases constructed in which the piston is pressed only in one direction by the steam. But such engines have not come into general use.

Q. Is not the circular motion derived from a cylinder engine very irregular, in consequence of the unequal leverage of the crank at the different parts of its revolution?

A. No; rotative engines are generally provided with a fly-wheel to correct such irregularities by its momentum; but where two engines with their respective cranks set at right angles are employed, the irregularity of one engine corrects that of the other with sufficient exactitude for some purposes. In the case of marine and locomotive engines, a fly-wheel is not employed; but there the momentum of the vessel or train accomplishes the same object. For cotton-spinning, and other purposes requiring great regularity of motion, a swift and heavy fly-wheel is indispensable.

Q. You implied that there is some other difference between single-acting and double-acting engines than that which lies in the use or exclusion of the crank?

A. Single-acting engines act only in one way by the force of the steam, and are returned by a counter-weight; whereas double-acting engines are urged by the steam in both directions. Engines, as I have already said, are sometimes made double-acting, though unprovided with a crank; and there would be no difficulty in so arranging the valves of all ordinary pumping engines, as to admit of this action; for the pumps might be contrived to raise water both by the upward and downward stroke, as, indeed, in some mines and many waterworks is already done. But engines without a crank are almost always made single-acting, perhaps from the effect of custom as much as from any other reason, and are usually spoken of as such, though it is necessary to know that there are some deviations from the usual practice.

NATURE AND USES OF A VACUUM.

Q. You have stated that a vacuum is an empty space. Can an empty space exert pressure? and does not a vacuum produce a pressure, by suction, of 15 lbs. per square inch?

A. I have stated that a vacuum is a space containing neither air, nor water, nor anything else that we know of. But it may contain things that we do *not* know of, and an absolutely perfect vacuum has never yet been obtained. Our ideas touching the nature of matter are still in a state of evolution, and any dictum in regard to its presence or absence should be propounded with corresponding diffidence. The kind of vacuum to which I referred is that which is producible by the air-pump, or which exists in the barometer, where it supports a column of mercury 30 inches high, which is equivalent to a pressure of about 15 lbs. per square inch.

Q. How can such a pressure be exerted by a vacuum which is itself destitute of matter or anything to produce pressure?

A. It is not the vacuum which exerts this pressure, but the atmosphere, which, like a head of water, presses on everything immerged beneath it. A head of water, however, would not press down a piston if the water were admitted on both of its sides; for an equilibrium would then be established, just as in the case of a balance which retains its equilibrium when an equal weight is added to each scale; but take the weight out of one scale, or empty the water from one side of the piston, and motion or pressure is produced. In like manner, pressure is produced on a piston by admitting steam or air upon the one side, and withdrawing the steam or air from the other side. It is not, therefore, to a vacuum, but rather to the existence of an unbalanced plenum, that the pressure made manifest by exhaustion is due, and it is obvious therefore that a vacuum of itself would not work an engine.

Q. How is the vacuum maintained in a condensing engine?

A. The steam, after having performed its office in the cylinder, is permitted to pass into a vessel, called the condenser, where a shower of cold water is discharged upon it. The steam is condensed by the cold water, and falls in the form of hot water to the bottom of the condenser. The water, which would else be accumulated in the condenser, is continually being pumped out by a pump worked by the engine. This pump is called the air-pump, because it also discharges any air which may have entered with the water. In some engines the steam is condensed by the application of cold metallic surfaces, as in a still. This is called surface condensation.

Q. If a vacuum be an empty space, and there be water in the condenser, how can there be a vacuum there?

A. There is a vacuum above the water, the water being only like so much iron or lead lying at the bottom.

Q. Is the vacuum in the condenser a perfect vacuum?

A. Not quite perfect; for the cold water entering for the purpose of condensation is heated by the steam, and emits a vapour of a tension represented by about three inches of mercury; that is, when the common barometer stands at thirty inches, a barometer with the space above the mercury communicating with the condenser will stand at about twenty-seven inches.

Q. Is this imperfection of the vacuum wholly attributable to the vapour in the condenser?

A. No; it is partly attributable to the presence of a small quantity of air which enters with the water, and which would accumulate until it destroyed the vacuum altogether but for the action of the air-pump, which expels it with the water, as already explained. All common water contains a certain quantity of air in solution, and this air recovers its elasticity when the pressure of the atmosphere is taken off,—just as the gas in soda water flies up so soon as the cork of the bottle is withdrawn.

Q. Is a barometer sometimes applied to the condensers of steam-engines, to ascertain the amount of exhaustion existing in the condenser?

A. Yes; and it is called the vacuum gauge, because it shows the degree of perfection the vacuum has attained. Another gauge, called the steam gauge, is applied to the boiler, which indicates the pressure of the steam by the height to which the steam forces mercury up a tube, or by some other suitable expedient. Gauges are also applied to the boiler to indicate the height of the water within it so that it may not be burned out by the water becoming accidentally too low. In some cases a succession of cocks, placed a short distance above one another, is employed for this purpose, and in other cases a glass tube is placed perpendicularly in the front of the boiler, and communicating at each end with its interior. The water rises in this tube to the same height as in the boiler itself, and thus shows the actual water level. In most of the modern boilers both of these contrivances are adopted.

Q. Can a condensing engine be worked with a pressure less than that of the atmosphere?

A. Yes, if once it be started; but it will be a difficult thing to start an engine if the pressure of the steam be not greater than that of the atmosphere. Before an engine can be started, it has to be blown through with steam to displace the air within it, and this cannot be effectually done if the pressure of the steam be very low. After the engine is started, however, the pressure in the boiler may be lowered, if the engine be lightly loaded, until there is a partial vacuum in the boiler. Such a practice, however, is not to be commended, as the gauge cocks become useless when there is a partial vacuum in the boiler, inasmuch as, when they are opened, the water will not rush out, but air will rush in. It is impossible, also, under such circumstances, to blow out any of the sediment collected within the boiler, which, in the case of the boilers of steam vessels not fitted with surface condensers, requires to be done every two hours or oftener. This is accomplished by opening a large cock which permits some of the supersalted water to be forced overboard by the pressure of the steam. In some cases, in which the boiler applied to an engine is of inadequate size, the pressure within the boiler will fall spontaneously to a point considerably beneath the pressure of the atmosphere. But it is preferable, in such cases, partially to close the throttle valve in the steam pipe. The pressure of the steam in the boiler is thus maintained, while the cylinder receives its former supply.

Q. If a hole be opened into the condenser of a steam engine, will air rush into it?

A. If the hole communicates with the atmosphere, the air will be drawn in.

Q. With what velocity will air rush into a vacuum?

A. Formerly it was supposed that air would rush into a vacuum with the velocity which a body would acquire by falling from the height of a homogeneous atmosphere, which is an atmosphere of the same density throughout as at the earth's surface; and although such an atmosphere does not exist in nature, its existence was supposed in order to facilitate the computation. It is well known that the velocity with which water issues from a cistern is the same that would be acquired by a body falling from the level of the head to the level of the issuing water; which, indeed, is an obvious law, since every particle of water descends and issues by virtue of its gravity, and is in its descent subject to the ordinary laws of falling bodies. Air rushing into a vacuum, it was contended, is only another example of the same general principle: so that the velocity of each particle should be that due to the height of the column of air which would produce the pressure sustained if there were no other disturbing force. The weight of air being known, as well as the pressure it exerts on the earth's surface, it is easy on this principle to tell what height a column of air an inch square, and of the atmospheric density, would require to be to weigh 15 lbs. The height would be 27,818 feet, and the velocity which the fall of a body from such a height produces is 1,338 feet per second.

Q. Are there not mountains on the earth's surface more than 27,818 feet high?

A. There are.

Q. Then is it contended that the tops of these mountains necessarily project beyond the limits of the atmosphere?

A. No; the atmosphere, it is believed, extends to a height of 45 miles, but with a constantly-diminishing density, until the weight of each particle balances its repulsive force, when the surface of the air will form a horizontal plane like a sheet of water.

Q. Then how can the velocity of air entering a vacuum be determined?

A. In the foregoing analysis, an important part of the action of the air has been left out of account; for the air is not merely drawn by suction into an orifice as water is, but, unlike water, expands in bulk at the same time, and a large part of the motion generated is expended in accomplishing this expansion. While, therefore, at low rates of exhaustion the velocity of air entering a vacuum does not differ much from that determined by the old theory as depending on the velocity of falling bodies, the divergence increases with the exhaustion; and if the vacuum be supposed to be quite perfect, the air would not enter it at all. The velocities, as determined by the old theory and the new, are as follows:—

Velocity of Air into a Partial Vacuum.

Pressure or Exhaustion in lbs.	Velocity in Feet per Second		Pressure or Exhaustion in lbs.	Velocity in Feet per Second	
	New Theory	Old Theory		New Theory	Old Theory
·5	249	247	8	673	986
1	337	349	8·5	669	1,016
1·5	405	427	9	661	1,046
2	459	493	9·5	650	1,074
2·5	503	551	10	636	1,103
3	540	604	10·5	619	1,129
3·5	571	652	11	597	1,156
4	597	697	11·5	571	1,183
4·5	619	739	12	540	1,208
5	636	780	12·5	503	1,232
5·5	650	818	13	459	1,257
6	661	854	13·5	405	1,281
6·5	669	889	14	337	1,304
7	673	922	14·5	242	1,327
7·5	675	955	15	000	1,350

Q. Has the velocity of the flow of air by the new theory been confirmed by experiment?

A. Yes. It was found by Mr. Froude, by experiment on the Croydon line of atmospheric railway, that the flow of air into the exhausted pipe was less rapid when the vacuum was high than when it was lower. This was at first attributed to a diminished leakage in the long valve which was placed on the upper side of the tube to permit the passage of the arm which connected the piston with the carriage, as it was supposed that with a high exhaustion the valve would be more firmly shut down. But it was found that this was not the true cause, and that the air flowed more rapidly into any vessel—whether furnished with a valve or not—if the vacuum were that due to a moderate exhaustion than if the vacuum were more perfect. The foregoing table shows that the velocity of influx is greatest when the exhaustion is that answering to 7½ lbs. per square inch, or midway between the atmospheric pressure and a perfect vacuum.

Q. What is meant by a Torricellian vacuum, and how is it produced?

A. It means the vacuum which exists above the mercury in an ordinary barometer-tube. To make a barometer, we take a glass tube, D, fig. 1, about a yard long and quarter of an inch bore, closed at one end but open at the other. Holding the open end upwards, we pour mercury into the tube until we fill it. The thumb is then placed on the open end, as at C, and the tube is inverted, the open end being placed below the surface of the mercury in the vessel B, before the thumb is withdrawn. The mercury will then subside to some such point as A, and the distance from A to the surface of the mercury in B will be about thirty inches. This is the height of a column of mercury which balances the pressure of the atmosphere. If water were to be used instead of mercury, the height of column necessary to balance the atmosphere would be about 34 feet, the water being so much lighter than the mercury. The subsidence of the mercury creates a vacuum within the tube above A, and this is called a Torricellian vacuum. This vacuum is not quite perfect, as it contains mercurial vapour of very small tension. The rise or fall in the surface of the mercurial column shows an increase or diminution in the pressure of the atmosphere, and this is what the barometer indicates.

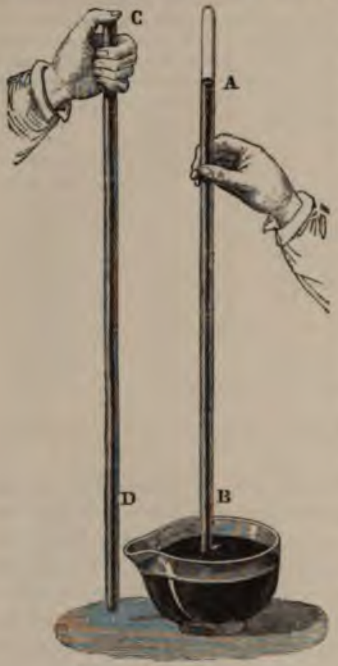


Fig. 1.—Mercurial Barometer.

Q. Are there other forms of barometer besides that with a mercurial column?

A. There are several other forms; one of the most convenient of which is the Aneroid, an example of which is shown in fig. 2. This instrument consists substantially of a small round metal box, within which a vacuum is made. The lid of the box is formed of a thin steel plate with concentric corrugations which enable it to bend in or out with every variation of pressure, and these variations give motion to a hand, which shows the amount of flexure, and, consequently, the amount of pressure due to the exhaustion.

Q. In what way is a vacuum generally produced for philosophical purposes?

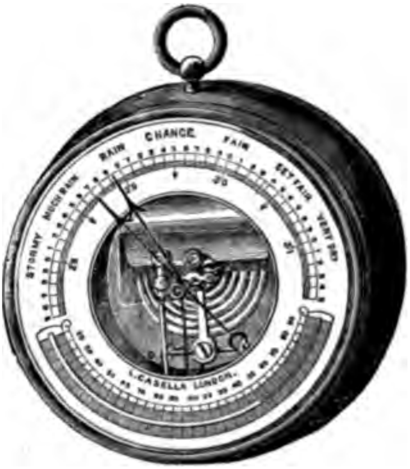


Fig. 2.—Aneroid Barometer.

A. By means of a small pump, called an air-pump; and which pumps the air out of any close vessel in much the same way in which any common house-pump draws water. An example of an air-pump of usual construction is shown in section in fig. 3, where VGQ is the frame or base of the machine, and R a bell-glass ground tight at its under edge upon the base-plate so that it will not leak when a vacuum is created within it. M N are handles by which motion to and fro is given to a toothed wheel, which works in a rack, H, which draws the piston, P′, up and down. The pump-barrel is secured to the frame at *m* L. A tube leads from *n* within the receiver R to the valve C, at the bottom of the pump-barrel. In the piston there is also a valve opening upwards, and as the piston is moved up and down, the air is drawn from *n* through the valve C, which valve shuts when the piston descends; but the air, compressed by the piston in its descent, lifts the valve in the piston and escapes into the atmosphere. E is a glass tube, which by means of the stopcock T can be put into communication with the pump; and within which there is a bent tube containing mercury, which shows the amount of the exhaustion attained. S is a pipe, and *r* a screw, which closes an orifice by which the external air may be admitted when desired. Fig. 4 shows an open receiver, or jar, the top closed with bladder. This jar, if placed on the plate of an air-pump, will have the bladder burst when the air is pumped out.

Q. Are the highest degrees of exhaustion produced by an air-pump of the construction you have now described?

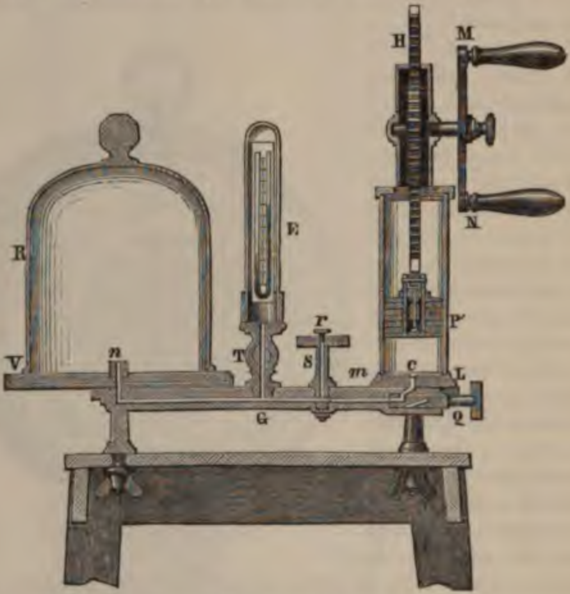


Fig. 3.—Air-pump.

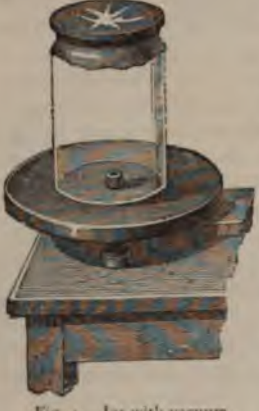


Fig. 4. Jar with vacuum.

A. No; a higher degree of exhaustion may be obtained with a simpler apparatus, called 'Sprengel's Air-pump,' and which consists substantially of a tall glass tube, through which drops of mercury are permitted to descend, and each drop constitutes a piston. The air is led into the tube through a side channel, and the successive drops of mercury propel the air before them in much the same way in which the pistons or discs of a chain-pump propel the water. A representation of this apparatus is given in fig. 5, where

A is a funnel into which the mercury is poured, and B is a bottle into which it subsides through the tube *cd*. R is the receiver, or vessel from which the air is drawn through the tube *x*. The funnel is connected to the upright glass tube at *c*, by a short piece of india-rubber tubing, a clamp applied to which determines the rate at which the mercury is allowed to descend. In some cases the mechanical exhaustion is supplemented by introducing some substance which has a chemical affinity for the residual air or gas, and which therefore absorbs it. It has been ascertained that electricity will not pass through a vacuum of a very high degree of exhaustion, and that matter in appreciable quantity must be present to enable the current to pass. A bell rung within a vacuum is inaudible.

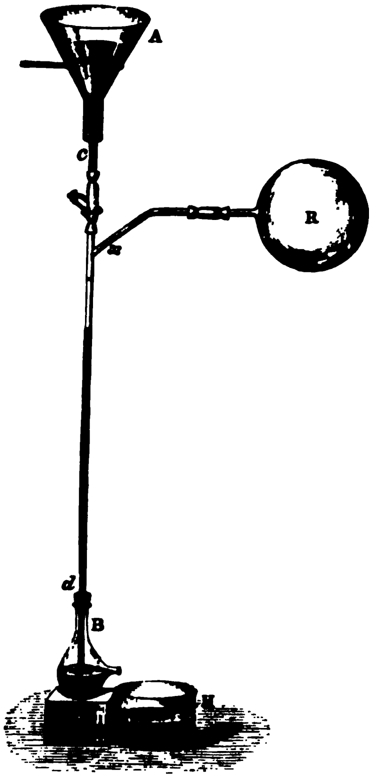


Fig. 5.—Sprengel's Air-pump.

Q. What do you mean by the ultra-gaseous state of matter?

A. In ordinary gases the molecules are believed to be in a state of constant motion, and the pressure or elasticity is supposed to be the result of the impact of the particles upon the containing vessel and upon one another, or of the centrifugal force of the revolving atmospheres by which each molecule is surrounded. When the gas is subjected to a high degree of rarefaction, the molecules can travel through considerable distances without impinging upon one another; and the mean wave-length or orbit is no longer infinitely small in comparison with the dimensions of the containing vessel. A new state of things is then produced presenting remarkable phenomena. Fig. 6 is a representation of 'Crookes' Radiometer,' formed with two light aluminium wires crossed, and with small squares of mica blackened on one side, attached to the ends of the cross wires. These wires constitute a fly which rests at the centre on a fine steel point on which the combination is able to rotate, and the whole is enclosed in a glass bulb, within which a Torricellian vacuum is produced. If now a light, such as a candle, be brought near one side of the instrument, the fly begins to rotate; as the blackened surfaces are drawn towards the light. If, however, the rarefaction be increased, the motion stops, and then the fly begins to rotate in the opposite direction. The most perfect vacuum will be produced by exhausting the gas by a Sprengel pump, and then absorbing the residual gas by chemical means. By proceeding in this way, Crookes obtained a vacuum of $\frac{1}{13000}$ millimètre of mercury —a millimètre being 0·0393 of an English inch. With the best air-pump of the common piston kind, the tension of the residual vapour, or gas, which cannot be extracted is about equal to $\frac{1}{30}$ of an inch of mercury. The pressure within a Torricellian vacuum may be taken at 0·19 millimètres of mercury.

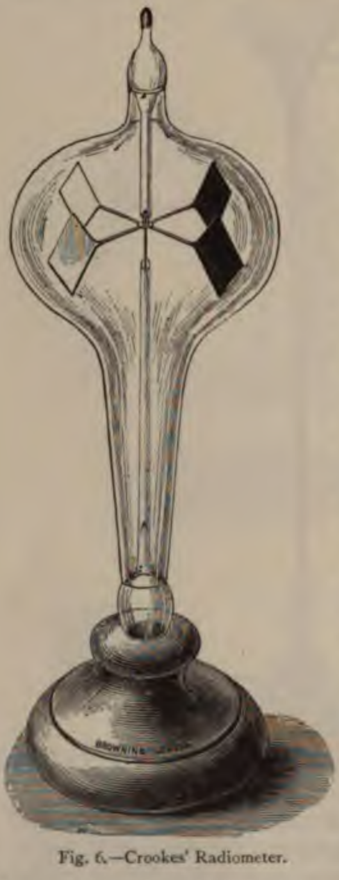


Fig. 6.—Crookes' Radiometer.

The repulsion excited by a light on a blackened surface at high rates of exhaustion increases as the pressure diminishes up to an exhaustion of 0·03 mm. It then sinks rapidly up to 0·000076 mm., when it is about $\frac{1}{10}$ of its maximum.

NATURE AND PROPERTIES OF MATTER.

Q. What is matter?

A. Anything capable of resisting or transmitting force.

Q. Is matter a continuous and homogeneous substance?

A. No; it is composed of atoms or particles, each of which is too small to be discernible by the senses. There is no reason to believe that these atoms touch one another, and each may be as far distant from its nearest neighbour relatively with its own magnitude as the earth is distant from the sun. A group of two or more atoms constitutes a molecule, just as the sun and his planets revolving in space constitute a sidereal system. Bodies, then, are composed or built up of very small molecules, and these again of smaller atoms.

Q. What are the different molecular states of bodies?

A. The solid, the liquid, and the gaseous, to which must now be added the ultra-gaseous, or the condition which gaseous bodies have been found to assume under high rates of rarefaction.

Q. Is there any limit to the expansive power of gases?

A. There appears to be a limit, which will be reached when the weight of each particle balances its repulsive force. In a long vertical tube, therefore, very highly exhausted, there may be matter at the lower part, but not at the upper.

Q. What are the essential properties of matter?

A. One is impenetrability, which renders it impossible for two bodies to occupy the same space at the same time. Another is extension or magnitude, in virtue of which every body occupies a limited portion of space. Another is divisibility, in virtue of which a body may be divided into any desired number of parts, the only limit to this being the atomic constitution of the body, as an atom cannot be divided, and a molecule, if divided, would be altered in its properties. Another is inertia, or that property which implies that a body at rest necessarily continues in that state unless some force be impressed upon it, or if in motion, such motion can only be terminated or altered by the application of force.

Q. Is weight a property of matter?

A. It is generally so considered. But for aught we know, there may be matter without weight. It does not necessarily follow, moreover, that the atoms of which matter is composed have any real magnitude, and according to Boscovich's hypothesis, they may be mere mathematical points, each surrounded by an atmosphere of force or heat.

Q. Are light and heat forms of matter?

A. No; light and heat are forms of motion. They are waves or undulations in a subtle fluid, or ether, supposed to penetrate all space; and electricity is believed to be another species of motion in the same fluid. This fluid has probably some weight and inertia, seeing that the light of the sun takes about eight minutes to reach the earth, and that electricity also takes a certain appreciable time to travel. But gravitation acts instantly, without any appreciable interval of time elapsing, and it appears probable, therefore, that gravitation is a motion propagated in a still lighter ether, or in one of no weight.

MOTION, TIME, SPACE, PRESSURE, AND POWER, OR WORK.

Q. What is motion?

A. Change of place.

Q. And what is time?

A. It is a record of the succession of events. The measure of time most generally employed is the motion of the heavenly bodies, by which the time of clocks is regulated.

Q. What is space?

A. Space may be of three kinds, namely: length or linear distance, which is a space of one dimension; of area or superficies, which is a space of two dimensions; and of capacity or bulk, which is a space of three dimensions. Mathematicians maintain that there may be spaces of four or more dimensions. But the demonstration of the soundness of this contention has not yet been made very intelligible to the public at large.

Q. What is pressure?

A. It is a force acting without motion, such as the force of gravity, acting on a heavy body lying on the surface of the earth.

Q. What is power?

A. Power, or work, is pressure acting through space, and the amount of the power is measurable by the amount of the pressure which acts through a given space in a given time, or by the amount of the space through which a given pressure acts in a given time.

Thus, in an engine, the pressure on the piston acting through the length of the stroke generates a certain amount of power per stroke, and this multiplied by the number of strokes made per minute, gives an expression for the power generated per minute. The velocity of the piston is measured by the distance travelled by it in a given time,—generally by the number of feet it passes through in the minute.

Q. Is there any unit of work, or *vis viva*, by which the power exerted by a machine or force is measured?

A. There are several such units; one is the work required to lift a pound weight a foot high, which is called a foot-pound, and another is the work required to lift 33,000 pounds a foot high in each minute of time, which is called a horse-power, this being the work which Mr. Watt found that the strongest horses could continuously perform. An ordinary cart horse, walking at its best speed, will advance about 216 feet per minute, and will in general draw, with a force of traction, about 120 lbs. It will thus perform only about 0·783 of the work assumed by Watt in the standard established by him. A man-power is usually taken at one-eighth of a horse-power. It is best exerted by the man ascending a ladder or stair, raising his own weight, say 143 lbs., 30 ft. per minute. The best load for an ox is the same as that for a horse, and the best velocity ⅔ that of a horse, making the work also ⅔. For a mule the velocity should be the same as that for a horse, and the load half as great, making the work also half; and for an ass the velocity should be about the same as for a horse or mule, and the load ¼ of that for a horse, making the work done also ¼.

Q. Can a force once called into existence be destroyed?

A. No; force is eternal if by force you mean power, or in other words, pressure acting through space. But if by force you mean mere pressure, then it furnishes no measure of power. Power is not measurable by force alone, but by force and velocity combined.

Q. Is there no loss of power by the use of the crank?

A. Not any. Many persons have supposed that there was a loss of power by the use of the crank, because at the top and bottom centres it is capable of exerting little or no power; but at those times there is little or no steam consumed, so that no waste of power is occasioned by the peculiarity. Those who imagine that there is a loss of power caused by the crank perplex themselves by confounding the vertical with the circumferential velocity. If the circle of the crank be divided by any number of equidistant horizontal lines, it will be obvious that there must be the same steam consumed, and the same power expended, when the crank pin passes from the level of one line to the level of the other, in whatever part of the circle it may be, those lines being indicative of equal ascents or descents of the piston. But it will be seen that the circumferential velocity is greater with the same expenditure of steam when the crank pin approaches the top and bottom centres; and this increased velocity relatively with the piston-travel exactly compensates for the diminished leverage, so that there is the same power given out by the crank in each of the divisions.

Q. Is not power lost when two moving bodies strike one another and come to a state of rest?

A. No, not even then. The bodies, if elastic, will rebound from one another with their original velocity; if not elastic, they will sustain an alteration of form, and heat or electricity will be generated of equivalent value to the power which has disappeared.

Q. Then, if mechanical power cannot be lost, and is being daily called into existence, must not there be a daily increase in the power existing in the world?

A. That appears probable, unless it flows back in the shape of heat or electricity to the celestial spaces. The source of mechanical power is the sun, which exhales vapours that descend in rain, to turn mills, or which causes winds to blow by the unequal rarefaction of the atmosphere. It is from the sun, too, that the power comes which is liberated in a steam engine. The solar rays enable plants to decompose carbonic acid gas, the product of combustion, and the vegetation thus rendered possible is the source of coal and other combustible bodies. The combustion of coal under a steam boiler, therefore, merely liberates the power which the sun gave out thousands of years before.

Q. Can you tell how much power the sun must have been exerting during twelve hours to separate a ton of carbon from the atmosphere?

A. Assuming that the sun works without waste, the power consumed in effecting the separation will be the same as that which would be generated in a perfect engine by the combustion of a ton of carbon: and the amount of this power is easily computable. If 2,240 lbs. of carbon have to be separated in twelve hours, one-twelfth of this must be separated in one hour, and one-sixtieth of this, or 3·1 lbs., will have to be separated every minute. Now, a thermal unit being the amount of heat necessary to raise 1 lb. of water 1 degree Fahr., and 1 lb. of carbon being able to raise 14,500 lbs. of water 1 degree, we have 14,500 × 3·1 = 44,950 thermal units expended per minute. Then we know, from the principles of thermo-dynamics, that the mechanical equivalent of a thermal unit is 772 lbs. weight raised through 1 foot. The mechanical equivalent, therefore, of 44,950 thermal units will be 44,950 × 772 = 34,701,400 foot-pounds expended per minute, and this divided by 33,000 = 1051·5 actual horses-power.

PARALLELOGRAM OF FORCES, EQUILIBRIUM OF FLUID PRESSURE, AND CAPILLARY ATTRACTION.

Q. How is the magnitude of different pressures or forces determined?

A. The weight of a body, or its pressure downward by gravitation, is usually determined by a balance, or pair of scales, such as is shown in fig. 7. The object to be weighed is placed in one scale, and a sufficient number of known weights is introduced into the other to establish an equilibrium, when the beam of the scales will be level. If we have several forces or pressures acting in

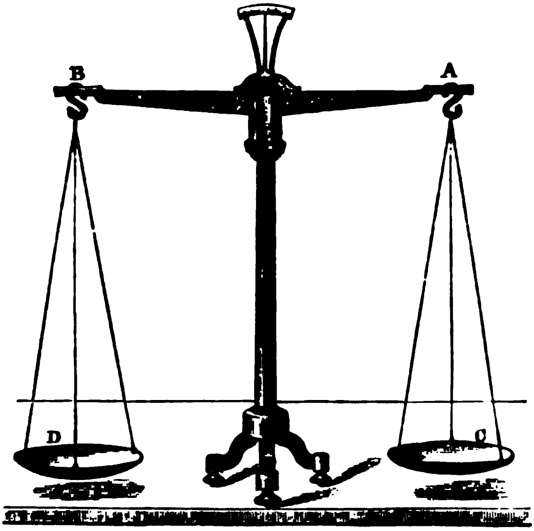


Fig. 7.—Pair of Scales.

different directions, the general result of them may be determined by the aid of the parallelogram of forces. If two forces act on a point, and if lines be drawn from that point representing both in direction and magnitude the forces or pressures operating, then if a parallelogram be constructed by the addition of equal and opposite lines, the resulting force or pressure will be represented both in magnitude and direction by the diagonal of the parallelogram. Thus, let H and K be two pulleys, and Q P weighted strings passing over the pulleys and fastened at A to another string, L, from which a weight, R, is suspended. Then, if we complete the parallelogram by adding the lines C D and B D, which are equal and opposite to C A and B A, representing Q and P, it will follow that the diagonal D A will represent both in magnitude and direction the strain or pressure exerted by the weight R.

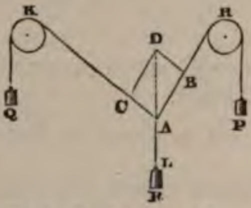


Fig. 8.—Parallelogram of Forces.

Q. What is meant by saying that water will always find its own level?

A. It means that just as in a tranquil lake the surface of the water is level, and no one part arises above another, so in a U tube, if water be poured in, it will stand at the same height in each leg. Nor will this law be altered if one leg be larger in diameter than the other, or if it be serpentine or inclined. In fig. 9, for example, the water stands at the same level in the vase D and in all the tubes A, B, C connected with it. So, in like manner, if we take a central vessel with pistons B, C, D, E fitted into its sides, then whatever pressure we impart to the contained liquid by the piston A will be equally operative upon all the other pistons. If, however, some of the pistons are made larger than others, those

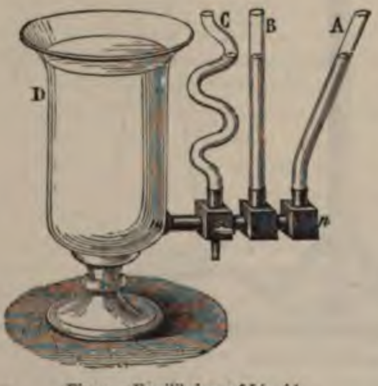


Fig. 9.—Equilibrium of Liquids.

which are the largest will be pressed out with the most force, the pressure being a determinate quantity per square inch of area, and those pistons which have the most square inches in their superficies will necessarily have the greatest collective pressure, just as many weights put into a pair of scales would necessarily preponderate over few. It is the property of fluids to propagate the pressure imparted to them equally in all directions, and it will be obvious that if the pistons B, C, D, and E be made very large relatively with A—or what comes to the same thing, if A be made very small relatively with the other pistons, then by applying a moderate force or pressure to A, the other pistons will be moved slowly outwards with very great force. Advantage is taken of this property in the construction of the hydraulic press, shown in fig. 11, where B is a cylinder within which a smooth plunger, or ram, works, made tight at the neck by a collar of leather *n*. *p* is a small plunger-pump into which water is sucked through a small valve, *o*, and is expelled through another valve, *o'*, through the pipe K into the cylinder B. *r* is a screw to let the water escape when desired. *i* is a safety-valve, and *h* is a screw to close the hole through which the valve *o'* has been introduced. Supposing the ram of the pump to be 1 inch, and the ram of the press 10

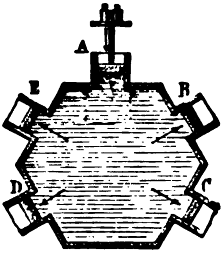


Fig. 10.—Fluid Pressure.

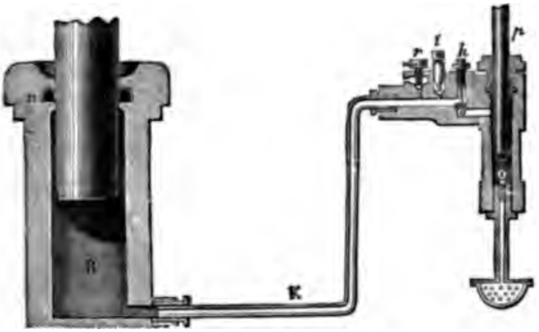


Fig. 11.—Hydraulic Press.

inches, then the ram of the press will be forced upwards with a hundred times the pressure with which the ram of the pump is forced down. If that be 100 lbs., then the ram of the press will be forced upward with a hundred times 100 lbs., or 10,000 lbs.

Q. You have stated that water in a tranquil state will necessarily all subside to the same level. If you take two squares of glass touching at one edge and slightly inclined to one another, as in fig. 12, and dip them in water, will not the water rise between them to a greater height than the level of the water outside, and will not the water be highest in the angle?

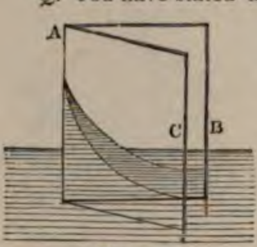


Fig. 12.

A. That will, no doubt, be so. But this does not interfere with the truth of the main proposition already propounded. Water will remain in very small tubes, and will not run out of them. But this is caused by an attraction existing between the glass, or other material of which the tube is composed, and the water. Owing to this attraction, the water rises to a somewhat higher point at the circumference of a small tube than it does at its centre. But in the case of mercury the reverse of this takes place, showing that such slight deviations from the general law are accidental to the material. If a small capillary tube containing water be electrified, the water will at once run out.

VIRTUAL VELOCITIES, THE MECHANICAL POWERS, DETERMINATION OF STRAINS.

Q. What is meant by the law of virtual velocities?

A. The law of virtual velocities lies at the root of mechanical philosophy, and its distinct apprehension affords a means of easy solution to a vast number of questions arising in engineering practice As power has been defined to be pressure acting through space, the amount of power will be determinable by the amount of the pressure multiplied by the amount of the space through which the pressure acts. A small pressure acting through a great space will represent as much power as a large pressure acting through a small space, the space multiplied by the pressure being in every case a constant quantity. Thus 33,000 lbs. raised 1 foot high in each minute represents a horse-power. But 1 lb. raised through

33,000 feet will equally represent a horse-power, or 16,500 lbs. raised through 2 feet, or 66,000 lbs. raised through 6 inches. When, therefore, we know the power, and also know the velocity, we can tell the pressure or strain, and we can so vary the proportion of the first and last velocities in any machine as to make the resulting pressure as great as we think fit.

Q. What do you understand by the mechanical powers?

A. The mechanical powers are certain contrivances, such as the wedge, the screw, the inclined plane, and other elementary machines, which convert a small force acting through a great space into a great force acting through a small space. In the school treatises on mechanics, a certain number of these devices are set forth as the mechanical powers, and each separate device is treated as if it involved a separate principle; but not a tithe of the contrivances which accomplish the stipulated end are represented in these learned works, and there is no very obvious necessity for considering the principle of each contrivance separately when the principles of all are one and the same. Every pressure acting with a certain velocity, or through a certain space, is convertible into a greater pressure acting with a less velocity, or through a smaller space; but the quantity of mechanical force remains unchanged by this transformation, and all that the implements called mechanical powers accomplish is to effect this transformation.

Q. Is there no power gained by the lever?

A. Not any; the power is merely put into another shape, just as the contents of a hogshead of porter are the same, whether they be let off by an inch tap or by a hole a foot in diameter. There is a greater gush in the one case than the other, but it will last a shorter time; when a lever is used there is a greater force exerted, but it acts through a shorter distance. It requires just the same expenditure of mechanical power to lift 1 lb. through 100 feet as to lift 100 lbs. through 1 foot. A cylinder of a given cubical capacity will exert the same power by each stroke, whether the cylinder be made tall and narrow, or short and wide; but in the one case it will raise a small weight through a great height, and in the other case, a great weight through a small height.

Q. Have no plans been projected for gaining power by means of a lever?

A. Yes, many plans—some of them displaying much ingenuity, but all displaying a complete ignorance of the first principles of mechanics, which teach that power cannot be gained by any multiplication of levers and wheels. I have occasionally heard persons say: 'You gain a great deal of power by the use of a capstan; why not apply the same resource in the case of a steam vessel, and increase the power of your engine by placing a capstan motion between the engine and paddle-wheels?' Others I have heard say: 'By the hydraulic press you can obtain unlimited power; why not, then, interpose a hydraulic press between the engines and the propeller?' To these questions the reply is sufficiently obvious. Whatever you gain in force you lose in velocity; and it would benefit you little to make the paddles revolve with ten times the force, if you at the same time caused them to make only a tenth of the number of revolutions. You cannot, by any combination of mechanism, get increased force and increased speed at the same time, or increased force without diminished speed: and it is from the ignorance of this inexorable condition that such myriads of schemes for the realisation of perpetual motion, by combinations of levers, weights, wheels, quicksilver, cranks, and other mere pieces of inert matter, have been propounded.

Q. Will you illustrate what you have stated by some examples?

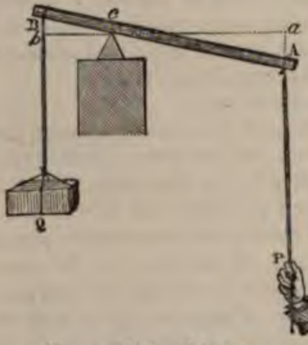


Fig. 13.—Action of the Lever.

A. In fig. 13, let A B be a lever, not with equal arms as in a pair of scales, but with the fulcrum *c* two-thirds from one end and one-third from the other, *a b* being the position when the lever is horizontal. It will follow that the pull at P is only half as great as the pull of the weight at Q; but then the space A *a*, passed through by the long end of the lever, is twice as great as the space B *b*, passed through by the short end. So again in the inclined plane, shown in fig. 14, R S is the plane, which may be set at any desired point of steepness or acclivity, R T being the horizontal length of the plane and S T its vertical height. *a* is a rolling weight, balanced on the plane by the weight P, hung at the end of a line passing over a pulley. Now, by the principle of virtual velocities, if the rise of the plane be 1 in 2, then for every two feet that the weight is moved along the plane in the direction

R S, it will be raised vertically one foot; or, in other words, while P falls a foot, *a* will only be raised vertically 6 inches. It will follow that 1 lb. added to the scale P will balance 2 lbs. added to the weight, *a*; or, in other words, the weight *a* will be in equilibrium on the plane when its gravity is twice that of the weights in P. The less the acclivity of the plane, the smaller will be the distance through which the weight is lifted vertically per foot of advance up the plane, and the less the traction will require to be; which is only saying that a gentle rise will be more easily surmounted than a steep one. If we describe the parallelogram *a c b d*, then *a c* will represent the pressure acting in the line of the plane, *a d* the pressure acting at right angles with the plane, and *a b* the vertical pressure.

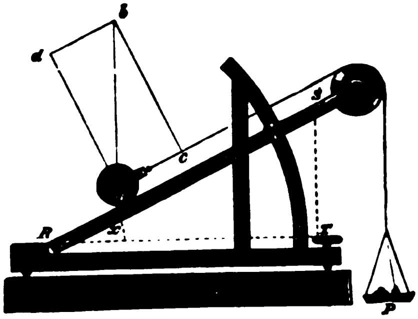


Fig. 14.—Inclined Plane.

Q. Is not the wedge a form of inclined plane?

A. The wedge, as shown by fig. 15, is two inclined planes set back to back, where *a b* is the driven end of the wedge, *c* its point, and *f g* the points where the splitting force acts. Draw the lines *f e* and *g e* at right angles with the splitting sides, and complete the parallelogram by drawing the dotted lines *f h* and *g h*. The diagonal *e h* will represent the resultant of the splitting resistances tending to force the wedge back.

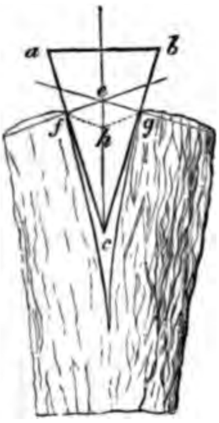


Fig. 15.—Wedge.

Q. Is not the screw in reality an inclined plane wound on a cylinder?

A. It is, as will be seen by considering the structure of a spiral stair, or by a reference to the annexed figures, where fig. 16 represents an inclined plane wound on a cylinder, the same letters showing the positions on the cylinder, and on the plane when drawn out. Fig. 17 represents an ordinary screw, and fig. 18 the nut in which it works.

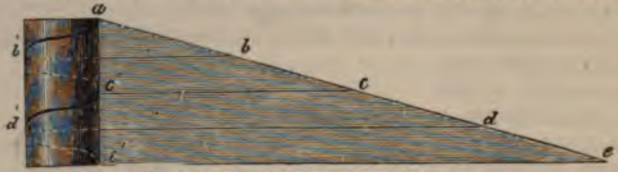


Fig. 16.—Inclined plane wound on Cylinder.

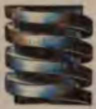


Fig. 17.

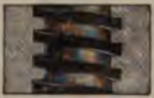


Fig. 18.

Q. Is the screw much used as a convenient instrument for creating strong local pressures and for moving heavy weights?

A. Machines of every kind are mostly held together by screw-bolts; and such instruments as screw-jacks, for lifting heavy weights, are also in extended use. One of these is shown in fig. 19, where A is the screw and B the nut, supported by short legs set on a sliding base, which may be moved longitudinally to some extent, either before the pressure has been put on or afterwards. C is the handle which turns round the screw by means of a ratchet-wheel formed on the body of the screw, and which is engaged by a pall inserted in the eye of the handle. The

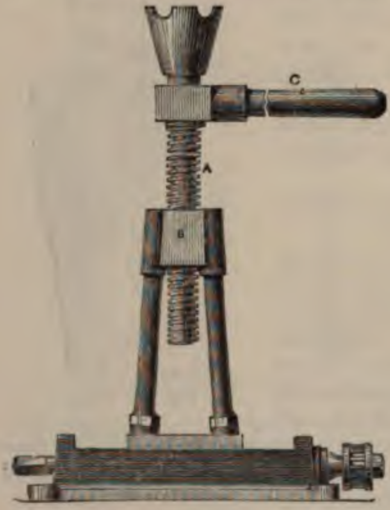


Fig. 19.—Screw jack.

handle may be made as long as is thought desirable. In the figure it has been broken short to contract the size of the cut.

Q. Will you show how the weight which can be lifted by a jack of this kind is to be determined?

A. The first thing is to fix the length of the handle and the force which is to be applied at the end of it. The next thing is to ascertain the pitch of the screw, or the vertical distance between the threads, which determines the distance through which it will be moved on end at each revolution. Suppose that the handle is 3 feet long, and that the pressure applied at the end of it to turn the screw is 30 lbs. Suppose, further, that the pitch of the screw is half an inch. As the handle moves in a circle of 72 inches diameter, or 226 inches circumference, it is clear that the initial and terminal velocities will be in the proportion of 226 to ½, or 452 to 1. In other words, the initial pressure of 30 lbs. will be increased 452 times by the machine, or it will be made 6,780 lbs., or over 3 tons. By doubling the pressure on the handle, the force of the jack will also be doubled; and just in the proportion of the increase of the force will be the diminution of the distance through which it acts per revolution.

Q. Will you show in what way the principle of virtual velocities can be applied to determine the weight which can be lifted by a rope and pulleys?

A. Nothing is simpler. If we lift a weight by a rope passing over a single pulley, as in fig. 20, the weight will be lifted as fast as the rope is drawn in; and, as in a pair of scales, the weight at one end of the rope will be balanced by an equal weight or pull at the other end. If, however, we introduce another pulley, as in fig. 21, it is clear that if we raise the weight suspended from the hook by 1 foot, we must pull down the rope through 2 feet, seeing that each of the two ropes has to be shortened a foot: and this length of rope, therefore, we must have pulled down. If we increase the number of pulleys, as in figs. 22 and 23, we must also increase the number of ropes, each of which has to be shortened a foot for each foot through which the weight is raised; and as these collective lengths have all to be pulled through the hands, the amount of pulling or space passed through by the rope in each foot of lifting will vary with the number of ropes, and just in the proportion of the space passed through will be the lifting power. A pair of blocks, therefore, connected by six turns of rope, each of which has to be shortened one foot for each foot that the weight is lifted, will lift a weight six times greater than the weight or pull imparted to the initial rope by which the pulling is performed.

Q. Does the same law apply in the case of wheelwork?

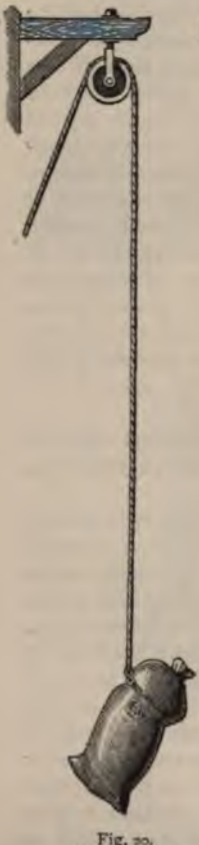


Fig. 20.
Simple lifting.

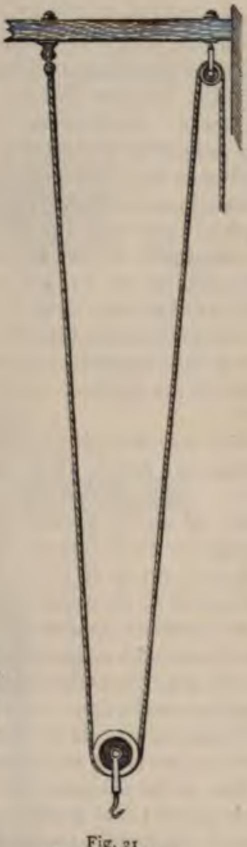
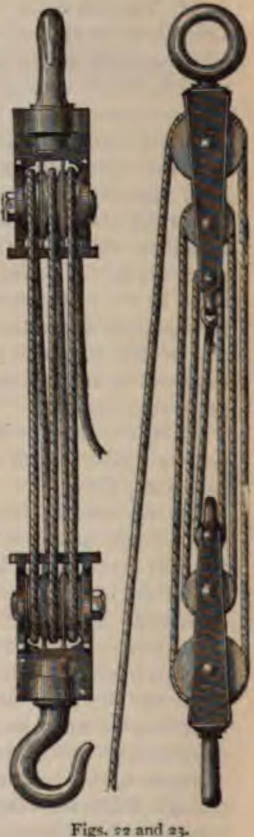


Fig. 21.
Composite lifting.



Figs. 22 and 23.
Pulley Blocks.

A. It applies in every case. In fig. 24 is represented a common form of crab winch employed to lift weights, A A being the handles, which are cut short in the cut to save space, B the barrel on which the rope is wound, and C and D a pinion and toothed wheel by which the motion of the handles is imparted to the barrel. If we want to determine what weight such a winch will lift, we have only to ascertain what amount of force is imparted to the handles and the circumferential distance through which they are moved at each revolution. If the surface of the barrel moves with one-sixth of the speed of the handles, then the weight which the rope will lift will be six times the weight or pressure exerted upon the handles, but it will only move through one-sixth of the distance in the same time.

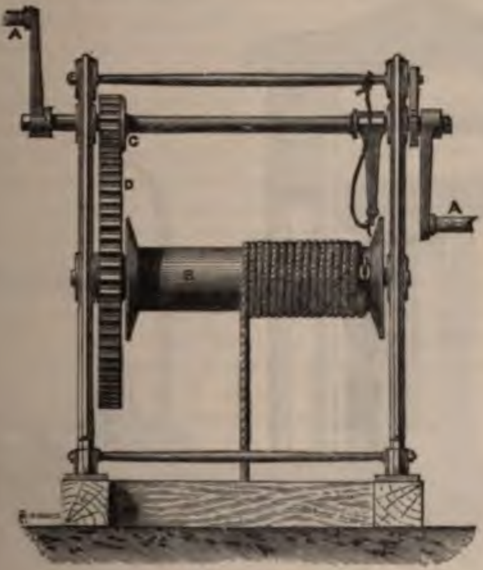


Fig. 24.—Hand Winch.

If we wish to lift a greater weight, we must make the rope move more slowly, either by the interposition of more toothed wheels or otherwise, the weight which can be lifted by any given initial force being in every case great in the direct ratio of the slowness of the motion with which the weight is raised.

Q. Then the same principle will also apply to the hydraulic press?

A. Certainly. As I have before stated, it applies to everything, and it is only on account of the great importance and universality of the principle that it is expedient to expend so much space in its exposition. An example of a hydraulic press is given in fig. 25, where A is the small pump by which the water is sent into the press, which water it draws through the rose *a*, set in the cistern H. B is the cylinder, and P the plunger, or ram, of the press, and *p* the plunger of the pump, which is worked by the handle M. A leather collar is interposed at the neck of the cylinder *n* to make the joint tight, and K is a tube for conveying the water from the pump to the press. In the best hydraulic presses two pumps are usually fitted; one, a large one, to bring the ram of the press up to its work rapidly, and the other, a small one, to impart a very high pressure when the table of the press has been brought up against the bale. Here, as in other cases, the pressure will be proportionate to the slowness of the motion, and the slower will be the motion the smaller is the pump. To introduce a smaller pump is tantamount to intro-

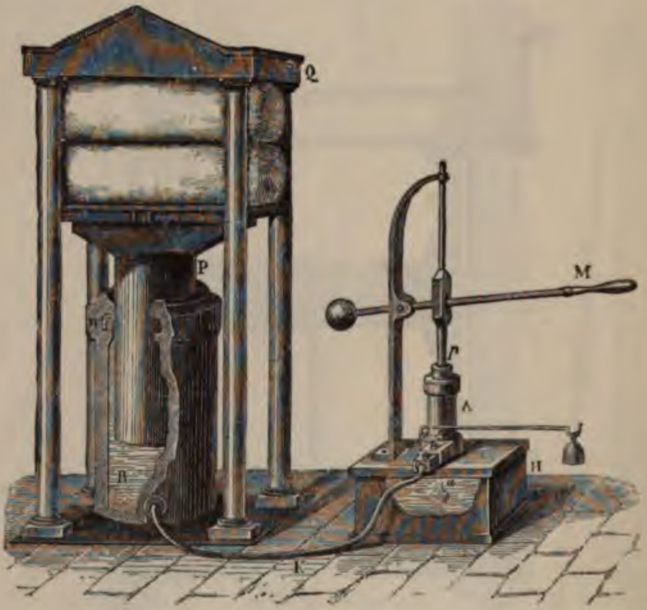


Fig. 25.–Hydraulic Press.

ducing a larger cylinder; and hence, the use of two pumps, either of which may be used as occasion arises, is to be commended.

Q. If the law of virtual velocities enables you to determine the pressures or strains to which machines are subjected, will it not also enable you to determine the strengths proper to be used in such machines to resist fracture?

A. It will; and not merely the strengths of machines, but the strengths proper for beams and structures of every kind. For although many of these objects, or the parts of them, have no velocity, and therefore no comparable elements, we have only to suppose them to break, which introduces the necessary element of motion; and we can thereafter deal with the strains or pressures existing at the breaking or moving parts, on the principle of virtual velocities, which enables the magnitude of those strains to be easily discovered. In any machine, such as a crane or winch, the strengths proper for the different parts are obviously dependent on the strains there subsisting, or, in other words, upon the slowness of the motion there subsisting; and this principle is applicable to the framing and other stationary parts, as well as to those parts which move, such as the wheels and axles. The handles of the crane, as but a small pressure or strain will be applied to them, need not be very strong, whereas the chain and chain-barrel, the jib, and the central pillar have to be strong enough to bear with safety the maximum weight the crane is intended to lift, and intermediate parts as they have intermediate velocities, and therefore intermediate strains, must also have intermediate strengths.

Q. But how, by the principle of virtual velocities, do you determine the strengths proper for stationary objects, such as a beam or cantilever, to resist any given strain?

A. Let fig. 26 represent a projecting beam or bracket fixed to a wall, and consisting of two wrought iron tubes, A A′, firmly fixed into the wall at one end, and securely united by an eye at the apex B, from which eye the weight W depends. In all iron beams the strength, other things being equal, depends upon the sectional area of the upper and lower flanges. If the beam be one supported at each end and loaded in the middle, the upper flange will be broken by compression and the lower by extension. But in an arrangement, such as that shown in fig. 26, the upper tube will be broken by extension and the lower by compression. At some place intermediate between the top and bottom flanges of a solid beam there will be a point called the neutral axis, where the metal is neither extended nor compressed. But all the metal above it is compressed when the beam is supported at the ends and loaded in the middle, and all the metal below the neutral axis is extended. The metal, however, in the web of the beam being unequally strained in proportion to its distance from the neutral axis, contributes very little to the strength, and so it is customary to regard the total strength as residing in the upper and lower flanges, and measurable by the sectional area of them. Now the tensile and crushing strength of all materials are not the same, and therefore, if the sectional areas of the top and bottom flanges are equal, the neutral axis will not lie in the middle of the web. But in the case of wrought iron the tensile and crushing strengths are nearly equal, and so the neutral axis of a wrought iron beam will be nearly in the middle of its depth. In the case of the combination shown in fig. 26, the pipes will tear by extension at *a*, and crush by compression at *a′* at the same

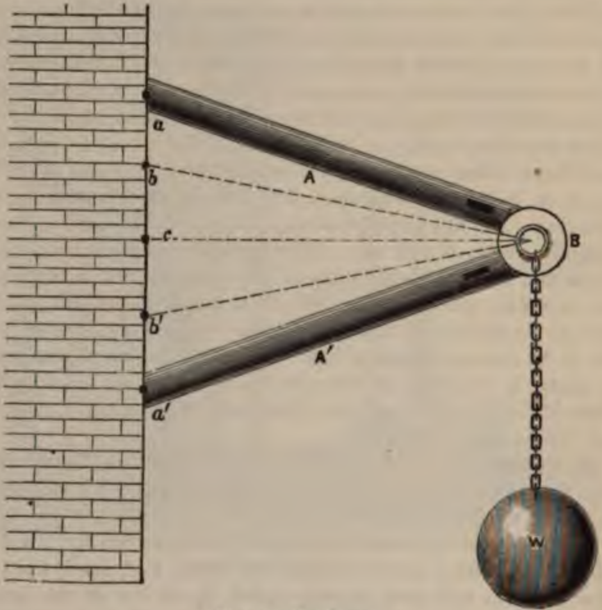


Fig. 26.—Cantilever.

moment, and *c* will be the neutral axis round which this tearing and crushing will take place. The dotted line *c a* and *c* B, therefore, form the arms of a bell crank lever, and the strain which any weight placed at W will exert will depend upon how much *c* B is greater than *c a*. If the distance between *a* and *a′* be the same as that between *c* and B, we have in such case a T lever, one of the arms of which draws and the other compresses with equal force, which is equivalent to having a bell crank with equal arms; or, taking the distance *c a* as half of the distance *c* B, a square inch of section of metal in the chain will be equal in strength to two square inches in the pipe at *a*. But, as half the strain is supported by the compression of the lower pipe at *a′*, it will follow that the conjoint strengths of a square inch extended at *a*, and of a square inch compressed at *a′*, will be equal to a square inch in the section of the chain. If the pipes be only spread half as much, as shown by the dotted lines *b b′*, the effective strength of each square inch of section of metal in the pipes will only be half as great, simply because the distance through which the fractured ends would move with any given descent of the weight would only be half as great, and the strain is measurable by the smallness of this motion.

Q. Will you further illustrate the application of this principle by taking the case of a wrought iron girder or beam, supported at the ends and loaded in the middle?

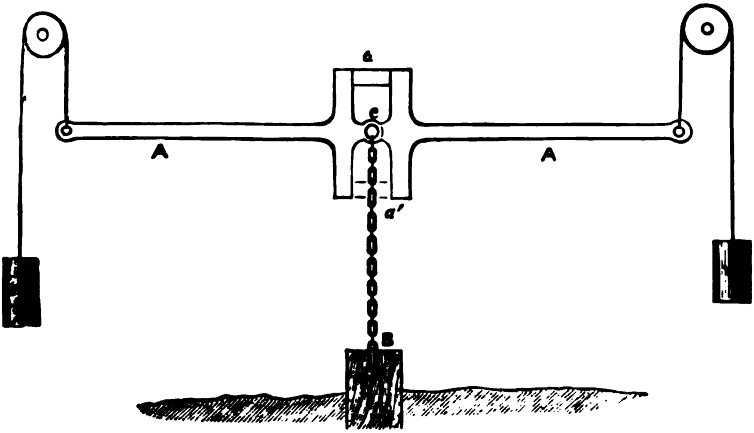


Fig. 27.—Beam loaded at Centre.

A. It is obvious that we may equally load a beam in the middle, by holding down its centre and pulling up its ends, as by supporting its ends and placing weight on its centre. Such an arrangement is shown in fig. 27, where A A are two T-shaped levers, the cross arms answering to the depth of the beam, and the long portions answering to half the length of the beam. *c* is the neutral axis secured by a chain to the post B, driven firmly into the ground. *a* answers to the position of the upper flange, which is compressed, and *a′* to the position of the lower flange, which is extended. Here as in the former case, the strain exerted by any given weight will be in the proportion of half the length of the beam to the depth. If, then, the length of the beam be 100 feet and its depth 10 feet, the strain will be five times greater than would be produced if an equal weight were hung upon the same sectional area of metal as in a chain; and the sectional area of the flanges must consequently be five times increased to give the same strength as the chain would have.

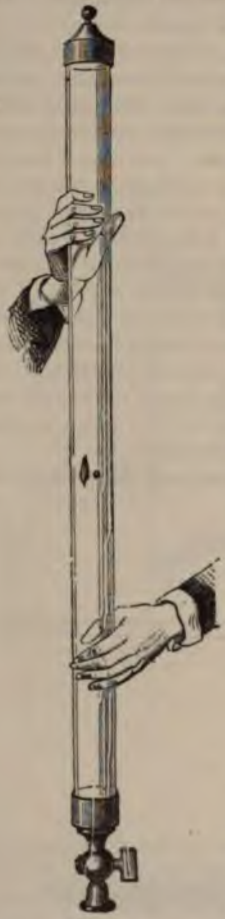


Fig. 28.
Guinea and Feather experiment.

VELOCITY OF FALLING BODIES AND MOMENTUM OF MOVING BODIES.

Q. How do you determine the velocity of falling bodies of different kinds?

A. All bodies fall with the same velocity, when there is no resistance from the atmosphere, as is shown by the experiment of letting fall, from the top of a tall exhausted receiver, a feather and a guinea, which reach the bottom at the same time. An illustration of this experiment is given in fig. 28. The velocity of falling bodies is one that is accelerated uniformly, according to a known law. When the height from which a body falls is given, the velocity acquired at the end of the descent can be easily computed. It has been found by experiment that the square root of the height in feet multiplied by 8·021 will give the velocity.

Q. But the velocity in what terms?

A. In feet per second. The distance through which a body falls by gravity in one second is $16\frac{1}{12}$ feet, in two seconds $64\frac{4}{12}$ feet, in three seconds, $144\frac{9}{12}$ feet, in four seconds, $257\frac{4}{12}$ feet, and so on. If the number of feet fallen through in one second be taken as unity, then the relation of the times to the spaces will be as follows:—

Number of seconds . . .	1	2	3	4	5	6	&c.
Units of space passed through . .	1	4	9	16	25	36	

so that it appears that the spaces passed through by a falling body are as the squares of the times of falling.

Q. Is not the urging force which causes bodies to fall the force of gravity?

A. Yes; the force of gravity or the attraction of the earth.

Q. And is not that a uniform force, or a force acting with a uniform pressure?

A. It is.

Q. Therefore during the first second of falling the same impelling pressure will be given by the force of gravity as during every succeeding second?

A. Undoubtedly.

Q. How comes it, then, that while the body falls $64\frac{4}{12}$ feet in two seconds, it falls only $16\frac{1}{12}$ feet in one second; or why, since it falls only $16\frac{1}{12}$ feet in one second, should it fall more than twice $16\frac{1}{12}$ feet in two?

A. Because there is more of the force of gravity used up in a second, when the falling body is moving fast, than when it is moving slowly, seeing that the fast body will travel through a larger space in a given time. The $16\frac{1}{12}$ feet is the average and not the maximum velocity during the first second. The velocity acquired *at the end* of the 1st second is not $16\frac{1}{12}$ but $32\frac{1}{6}$ feet per second, and at the end of the 2nd second a velocity of $32\frac{1}{6}$ feet has to be added; so that the total velocity at the end of the 2nd second becomes $64\frac{2}{6}$ feet: at the end of the 3rd, the velocity becomes $96\frac{3}{6}$ feet, at the end of the 4th, $128\frac{4}{6}$ feet, and so on. These numbers proceed in the progression 1, 2, 3, 4, &c., so that it appears that the velocities acquired by a falling body at different points, are simply as the times of falling, or the velocity is simply proportionate to the time during which the force of gravity acts. But if the velocities be as the times, and the total space passed through be as the squares of the times, then the total space passed through must be as the squares of the velocity; and as the power inherent in a falling body, of any given weight, is measurable by the height through which it descends, it follows that the power inherent in a moving body of any weight, or the *vis viva* as it is sometimes called, is proportionate to the square of the velocity. Of two balls, therefore, of equal weight, but one moving twice as fast as the other, the faster ball has four times the mechanical force accumulated in it that the slower ball has. If the speed of a fly-wheel be doubled, it has four times the *vis viva* it possessed before—*vis viva* being measurable by a reference to the height through which a body must have fallen, to acquire the velocity given.

Q. By what considerations is the *vis viva* or mechanical energy proper for the fly-wheel of an engine determined?

A. By a reference to the power produced every half-stroke of the engine, joined to the consideration of what relation the energy of the fly-wheel rim must have thereto, to keep the irregularities of motion within the limits which are admissible. It is found in practice that when the power resident in the fly-wheel rim, when the engine moves at its average speed, is from two and a-half to four times greater than the power generated by the engine in one half-stroke—the variation depending on the energy inherent in the machinery the engine has to drive and the equability of motion required—the engine will work with sufficient regularity for many purposes, but where great equability of motion is required, it will be advisable to make the power resident in the fly-wheel equal to six times the power generated by the engine in one half-stroke. Thus in a cylinder of 6½ inches diameter and 13 inches stroke, working with an average pressure of steam of 70 lbs. per square inch, and making 277 revolutions per minute, the area of cylinder will be 33 square inches, and the pressure on the piston 33 × 70 = 2310 lbs. The *vis viva* of six half-strokes will be 2310 lbs. × 6½ ft. = 15015 foot-pounds. If the diameter of the fly-wheel be 3½ feet, its circumference will be 11 feet, and the velocity of its rim 277 × 11 = 3047 ft. per minute, or 50·8 ft. per second. The height from which a body must fall by gravity to acquire this velocity is 40 feet, and 15,015 foot-pounds divided by 40 gives 375·4 lbs. as the weight which the rim of the fly-wheel will require to have in this case to possess an energy equal to six half-strokes of the piston.

Q. Can you give a practical rule for determining the proper quantity of cast iron for the rim of a fly-wheel in ordinary land engines?

A. One rule frequently adopted is as follows: multiply the mean diameter of the rim by the number of its revolutions per minute, and square the product for a divisor; divide the number of actual horse-power of the engine by the number of strokes the piston makes per minute, multiply the quotient by the constant number 2,760,000, and divide the product by the divisor found as above; the quotient is the requisite quantity of cast iron in cubic feet to form the fly-wheel rim.

Q. What is Boulton and Watt's rule for finding the dimensions of the fly-wheel?

A. Boulton and Watt's rule for finding the dimensions of the fly-wheel is as follows:—Multiply 44,000 times the length of the stroke in feet by the square of the diameter of the cylinder in inches, and divide the product by the square of the number of revolutions per minute multiplied by the cube of the diameter of the fly-wheel in feet. The resulting number will be the sectional area of the rim of the fly-wheel in square inches.

CENTRAL FORCES.

Q. What do you understand by centrifugal and centripetal forces?

A. By centrifugal force I understand the force with which a revolving body tends to fly from the centre; and by centripetal force I understand any force which draws it to the centre, or counteracts the centrifugal tendency. In the conical pendulum, or steam-engine governor, which consists of two metal balls suspended on rods hung from the end of a vertical revolving shaft, the centrifugal force is manifested by the divergence of the balls when the shaft is put into revolution; and the centripetal force, which in this instance is gravity, predominates so soon as the velocity is arrested; for the arms then collapse and hang by the side of the shaft.

Q. What measures are there of the centrifugal force of bodies revolving in a circle?

A. The centrifugal force of bodies revolving in a circle increases as the diameter of the circle, if the number of revolutions remain the same. If there be two fly-wheels of the same weight, and making the same number of revolutions per minute, but the diameter of one be double that of the other, the larger will have double the amount of centrifugal force. The centrifugal force of the *same wheel*, however, increases as the square of the velocity; so that if the velocity of a fly-wheel be doubled, it will have four times the amount of centrifugal force.

Q. Can you give a rule for determining the centrifugal force of a body of a given weight moving with a given velocity in a circle of a given diameter?

A. Yes. If the velocity in feet per second be divided by 4·01, the square of the quotient will be four times the height in feet from which a body must have fallen to have acquired that velocity. Divide this quadruple height by the diameter of the circle, and the quotient is the centrifugal force in terms of the weight of the body, so that, multiplying the quotient by the actual weight of the body, we have the centrifugal force in pounds or tons. Another rule is to multiply the square of the number of revolutions per minute by the diameter of the circle in feet, and to divide the product by 5,870. The quotient is the centrifugal force in terms of the weight of the body.

Q. How do you find the velocity of the body when its centrifugal force and the diameter of the circle in which it moves are given?

A. Multiply the centrifugal force in terms of the weight of the body by the diameter of the circle in feet, and multiply the square root of the product by 4·01; the result will be the velocity of the body in feet per second.

Q. Will you illustrate this by finding the velocity at which two cast-iron balls connected by a cast-iron bar, and rotated as a fly-wheel 10 feet in diameter, would burst asunder by their centrifugal force?

A. If we take the tensile strength of cast iron at 15,000 lbs. per square inch, a bar of two square inches of sectional area would sustain 30,000 lbs. If we suppose one ball and half of the bar to be so fixed to the shaft as to be incapable of detachment, then the centrifugal force of the other ball and half of the bar at the moment of rupture must be equal to 30,000 lbs. Now 30,000 lbs. divided by 49·48 (the weight of the half body) is equal to 606·3, which is the centrifugal force in terms of the weight. Then, by the rule given in the last answer, 606·3 × 10 = 6,063, the square root of which is 78 nearly, and 78 × 4·01 = 312·78, the velocity of the centre of the balls in feet per second at the moment of rupture.

Q. What is the greatest velocity at which it is safe to drive a cast-iron fly-wheel?

A. If we take 2,000 lbs. as the utmost strain per square inch to which cast iron can be permanently subjected with safety; then, by a similar process to that just explained, we have 4,000 lbs ÷ 49·48 = 80·8, which, multiplied by 10, = 808, the square root of which is 28·4, and 28·4 × 4·01 = 113·884, the velocity of the rim in feet per second. But as the bursting force acts in all directions, it will be less in any one direction in the proportion of the diameter of a circle to a semicircle, or 1 to 1·5708.

Q. What is the velocity at which the wheels of railway trains may run if we take 4,000 lbs. per square inch as the greatest strain to which malleable iron should be subjected?

A. The weight of a malleable iron rim of one square inch sectional area and 7 feet diameter is 21·991 feet × 3·4 lbs. = 74·76, one half of which is 37·4 lbs. Then, by the same process as before, 8,000 ÷ 37·4 = 213·9, the centrifugal force in terms of the weight. But as this has to be increased in the ratio of the length of a semicircle to a diameter, or about 1·5 times, 213·9 × 1·5 × 7, the diameter of the wheel = 2595·95, the square root of which, 51 × 4·01 = 224 feet per second, the highest velocity of the rims of railway carriage wheels that is consistent with safety. 224 feet per second is equivalent to about 150 miles an hour. As 4,000 lbs. per square inch of sectional area is the utmost strain to which iron should be exposed in machinery subject to shocks, railway wheels, if made of iron, can scarcely be considered safe at a speed even considerably under 150 miles an hour, unless effectually tied in by the arms or made of steel. Hooped wheels are very unsafe, unless the hoops are, by some process or other, firmly attached to the arms. It is of no use to increase the dimensions of the rim of a wheel with the view of giving increased strength to counteract the centrifugal force, as every increase in the weight of the rim will increase the centrifugal force in the same proportion.

CENTRES OF GRAVITY, GYRATION, AND OSCILLATION.

Q. What do you understand by the centre of gravity of a body?

A. That point within it in which the whole of the weight may be supposed to be concentrated, and which continually endeavours to gain the lowest possible position. A body hung in the centre of gravity will remain at rest in any position.

Q. What is meant by the centre of gyration?

A. The centre of gyration is that point in a revolving body in which the whole momentum may be conceived to be concentrated, or in which the whole effect of the momentum resides. If the ball of a governor were to be moved in a straight line, the momentum might be said to be concentrated at the centre of gravity of the ball; but inasmuch as, by its revolution round an axis, the part of the ball furthest removed from the axis moves more quickly than the part nearest to it, the momentum cannot be supposed to be concentrated at the centre of gravity, but at a point further removed from the central shaft, and that point is what is called the centre of gyration. The centre of gyration is the same as the centre of percussion.

Q. And what is the centre of percussion?

A. If a hammer, moved in an arc of a circle, be brought down on a nail at the point of the face furthest from the hand, it will not strike fair, but will tend to bend down the handle. If struck by the opposite point of the face, the tendency will be to bend up the handle. There is an intermediate point where one tendency balances the other, and that point is called the centre of percussion.

Q. What is the centre of oscillation?

A. The centre of oscillation is a point in a pendulum or any swinging body, such, that if all the matter of the body were to be collected into that point the velocity of its vibration would remain unaffected. It is, in fact, the mean distance from the centre of suspension of every atom, in a ratio which happens not to be an arithmetical one. The centre of oscillation is always in a line passing through the centre of suspension and the centre of gravity.

THE PENDULUM AND GOVERNOR.

Q. By what circumstance is the velocity of vibration of a pendulous body determined?

A. By the length of the suspending rod only, or, more correctly, by the distance between the centre of suspension and the centre of oscillation. The length of the arc described does not signify, as the times of vibration will be the same, whether the arc be the fourth or the four hundredth of a circle, or at least they will be nearly so, and would be so exactly if the curve described were a portion of a cycloid. In the pendulums of clocks, therefore, a small arc is preferred, as there is, in that case, no sensible deviation from the cycloidal curve, but in other respects the size of the arc does not signify.

Q. If, then, the length of a pendulum be given, can the number of vibrations in a given time be determined?

A. Yes; the time of vibration bears the same relation to the time in which a body would fall through a space equal to half the length of the pendulum that the circumference of a circle bears to its diameter. The number of vibrations made in a given time by pendulums of different lengths is inversely as the square roots of their lengths.

Q. Then when the length of the seconds pendulum is known, the proper length of a pendulum to make any given number of vibrations in the minute can readily be computed?

A. Yes; the length of the seconds pendulum being known, the length of another pendulum required to perform any given number of vibrations in the minute may be obtained by the following rule: multiply the square root of the given length by 60, and divide the product by the given number of vibrations per minute; the square of the quotient is the length of pendulum required. Thus, if the length of a pendulum were required that would make 70 vibrations per minute in the latitude of London, then $\frac{\sqrt{39\cdot1393}\times 60}{70} = 5\cdot363^2 = 28\cdot75$ in., which is the length required.

Q. Can you explain how it comes that the length of a pendulum determines the number of vibrations it makes in a given time?

A. Because the length of the pendulum determines the steepness of the circle in which the body moves, and it is obvious that a body will descend more rapidly over a steep inclined plane, or a steep arc of a circle, than over one in which there is but a slight inclination. The impelling force is gravity, which urges the body with a force proportionate to the distance descended, and if the velocity due to the descent of a body through a given height be spread over a great horizontal distance, the speed of the body must be slow in proportion to the greatness of that distance. It is clear, therefore, that as the length of the pendulum determines the steepness of the arc, it must also determine the velocity of vibration.

Q. If the motions of a pendulum be dependent on the speed with which a body falls, then a certain ratio must subsist between the distance through which a body falls in a second, and the length of the seconds pendulum?

A. And so there is; the length of the seconds pendulum at the level of the sea in London is 39·1393 inches, and it is from the length of the seconds pendulum that the space through which a body falls in a second has been determined. As the time in which a pendulum vibrates is to the time in which a heavy body falls through half the length of the pendulum, as the circumference of a circle is to its diameter, and as the height through which a body falls is as the square of the time of falling, it is clear that the height through which a body will fall, during the vibration of a pendulum, is to half the length of the pendulum as the square of the circumference of a circle is to the square of its diameter, namely, as 9·8696 is to 1; or it is to the whole length of the pendulum as the half of this, namely, 4·9348 is to 1; and 4·9348 times 39·1393 inches is 16 and 1-12 feet very nearly, which is the space through which a body falls by gravity in a second.

Q. Are the motions of the conical pendulum or governor reducible to the same laws which apply to the common pendulum?

A. Yes; the motion of the conical pendulum may be supposed to be compounded of the motions of two common pendulums vibrating at right angles to one another, and one revolution of a conical pendulum will be performed in the same time as two vibrations of a common pendulum, of which the length is equal to the vertical height of the point of suspension above the plane of revolution of the balls.

Q. Is not the conical pendulum or governor of a steam engine driven by the engine?

A. Yes.

Q. Then will it not be driven round as any other mechanism would be at a speed proportional to that of the engine?

A. It will.

Q. Then how can the length of the arms affect the time of revolution?

A. By flying out until they assume a vertical height answering to the velocity with which they rotate round the central axis. As the speed is increased the balls expand, and the height of the cone described by the arms is diminished, until its vertical height is such that a pendulum of that length would perform two vibrations for every revolution of the governor. By the outward motion of the arms, they partially shut off the steam from the engine. If, therefore, a certain expansion of the balls be desired, and a certain length be fixed upon for the arms, so that the vertical height of the cone is fixed, then the speed of the governor must be such that it will make half the number of revolutions in a given time that a pendulum equal in length to the height of the cone would make of vibrations. The rule is, multiply the square root of the height of the cone in inches by 0·31986, and the product will be the right time of revolution in seconds. If the number of revolutions and the length of the arms be fixed, and it is wanted to know what is the diameter of the circle described by the balls, you must divide the constant number 187·58 by the number of revolutions per minute, and the square of the quotient will be the vertical height in inches of the centre of suspension above the plane of the balls' revolution. Deduct the square of the vertical height in inches from the square of the length of the arm in inches, and twice the square root of the remainder is the diameter of the circle in which the centres of the balls revolve.

Q. Cannot the operation of a governor be deduced merely from the consideration of centrifugal and centripetal forces?

A. It can, and by a very simple process. The horizontal distance of the arm from the spindle divided by the vertical height will give the centripetal force, and the velocity of revolution requisite to produce an equivalent centrifugal force may be found by multiplying the centripetal force of the ball in terms of its own weight by 70,440, and dividing the product by the diameter of the circle made by the centre of the ball in inches; the square root of the quotient is the number of revolutions per minute. By this rule you fix the length of the arms, and the diameter of the base of the cone, or, what is the same thing, the angle at which it is desired the arms shall revolve, and you then make the speed or number of revolutions such that the centrifugal force will keep the balls in the desired position.

Q. Does not the weight of the balls affect the question?

A. Not in the least; each ball may be supposed to be made up of a number of small balls or particles, and each particle of matter will act for itself. Heavy balls attached to a governor are only requisite to overcome the friction of the throttle valve which shuts off the steam, and of the connections leading thereto. Though the weight of a ball increases its centripetal force, it increases its centrifugal force in the same proportion.

FRICTION.

Q. What is friction?

A. Friction is the resistance experienced when one body is rubbed upon another body, and is supposed to be the result of the natural attraction which bodies have for one another, and of the interlocking of the impalpable asperities upon the surfaces of all bodies, and these combined agencies produce such internal motions among the particles of a rubbing surface as to generate heat, which heat will always be of equivalent value to the power expended in overcoming the friction. It is found that as much power is expended in heating a pound of water one degree by friction as would raise a pound weight 772 feet high; and this measure of power is consequently termed the *mechanical equivalent* of the heat. The friction of the smooth rubbing substances is less when the composition of those substances is different than when it is the same, the particles being supposed to interlock less when the opposite prominences or asperities are not coincident.

Q. Does friction increase with the extent of rubbing surface?

A. No; the friction, so long as there is no violent heating or abrasion, is simply in the proportion of the pressure keeping the surfaces together, or nearly so. It is, therefore, an obvious advantage to have the bearing surfaces of steam engines as large as possible, as there is no increase of friction by extending the surface, while there is a great increase in the durability. When the bearings of an engine are made too small, they very soon wear out.

Q. Does friction increase in the same ratio as velocity?

A. No; friction does not increase with the velocity at all, if the friction over a given amount of surface be considered;* but it increases as the velocity, if the comparison be made with the time during which the friction acts. Thus the friction of each stroke of a piston is the same whether it makes twenty strokes in the minute or forty: in the latter case, however, there are twice the number of strokes made, so that, though the friction per stroke is the same, the friction per minute is doubled. The friction, therefore, of any machine per hour varies as the velocity, though the friction per revolution remains, at all ordinary velocities, the same. Of excessive velocities we have not sufficient experience to enable us to state with confidence whether the same law continues to operate among them.

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* This statement refers only to the friction of solids, and not of liquids, which comes under a different law, as explained further on.

Q. Can you give any approximate statement of the force expended in overcoming friction?

A. It varies with the nature of the rubbing bodies. The friction of iron sliding upon iron has generally been taken at about one-tenth of the pressure, when the surfaces are oiled and then wiped again, so that no film of oil is interposed. The friction of iron rubbing upon brass has generally been taken at about one-eleventh of the pressure under the same circumstances; but in machines in actual operation, where a film of some lubricating material is interposed between the rubbing surfaces, it is not more than one-third of this amount, or $\frac{1}{33}$rd of the weight. While this, however, is the average result, the friction is a good deal less in some cases. Mr. Southern, in some experiments upon the friction of the axle of a grindstone— an account of which may be found in the 65th volume of the 'Philosophical Transactions'—found the friction to amount to less than $\frac{1}{40}$th of the weight; and Mr. Wood, in some experiments upon the friction of locomotive axles, found that by ample lubrication the friction might be made as little as $\frac{1}{60}$th of the weight. In some experiments upon the friction of shafts by Mr. G. Rennie, he found that with a pressure of from 1 to 5 cwt. the friction did not exceed $\frac{1}{39}$th of the pressure when tallow was the unguent employed; with soft soap it became $\frac{1}{34}$th. The fact appears to be that the amount of the resistance denominated friction depends, in a great measure, upon the nature of the unguent employed, and in certain cases the viscidity of the unguent may occasion a greater retardation than the resistance caused by the attrition. In watch-work, therefore, and other fine mechanism, it is necessary both to keep the bearing surfaces small, and to employ a thin and limpid oil for the purpose of lubrication, for the resistance caused by the viscidity of the unguent increases with the amount of surface, and the amount of surface is relatively greater in the smaller class of works.

Q. Is a very thin unguent preferable also for the larger class of bearings?

A. The nature of the unguent proper for different bearings appears to depend in a great measure upon the amount of the pressure to which the bearings are subjected,—the hardest unguents being best where the pressure is greatest. The function of lubricating substances is to prevent the rubbing surfaces from coming into contact, whereby abrasion would be produced, and unguents are effectual in this respect in the proportion of their viscidity ; but if the viscidity of the unguent be greater than what suffices to keep the surfaces asunder, an additional resistance will be occasioned ; and the nature of the unguent selected should always have reference, therefore, to the size of the rubbing surfaces, or to the pressure per square inch upon them. With oil, the friction appears to be a minimum when the pressure on the surface of a bearing is about 90 lbs. per square inch. The friction from too small a surface increases twice as rapidly as the friction from too large a surface, added to which, the bearing, when the surface is too small, wears rapidly away.

Q. Has not General Morin, in France, made some very complete experiments to determine the friction of surfaces of different kinds sliding upon one another?

A. He has ; but the result does not differ materially from what is stated above, though, upon the whole, General Morin found the resistance due to friction to be somewhat greater than it has been found to be by various other engineers. When the surfaces were merely wiped with a greasy cloth, but had no film of lubricating material interposed, the friction of brass upon cast iron he found to be ·107, or about $\frac{1}{10}$th of the load, which was also the friction of cast iron upon oak. But when a film of lubricating material was interposed, he found that the friction was the same whether the surfaces were wood on metal, wood on wood, metal on wood, or metal on metal ; and the amount of the friction in such case depended chiefly on the nature of the unguent. With a mixture of hog's lard and olive oil interposed between the surfaces, the friction was usually from $\frac{1}{12}$th to $\frac{1}{14}$th of the load, but in some cases it was only $\frac{1}{20}$th of the load.

Q. May water be made to serve for purposes of lubrication?

A. Yes, water will answer very well if the surface be very large relatively to the pressure; and in screw vessels, where the propeller shaft passes through a long pipe at the stern, the stuffing box is purposely made a little leaky. The small leakage of water into the vessel which is thus occasioned keeps the screw shaft in this situation always wet, and this is all the lubrication which this bearing requires or obtains.

Q. What is the utmost pressure which may be employed, without heating, when oil is the lubricating material?

A. That will depend upon the velocity. When the pressure exceeds 800 lbs. per square inch, however, upon the section of the bearing in a direction parallel with the axis, then the oil will be forced out, and the bearing will necessarily heat.

Q. But, with a given velocity, can you tell the limit of pressure which will be safe in practice, or with a given pressure, can you tell the limit of velocity?

A. Yes; that may be done by the following empirical rule, which has been derived from observations made upon bearings of different sizes and moving with different velocities. Divide the number 70,000 by the velocity of the surface of the bearing in feet per minute. The quotient will be the number of pounds per square inch of section in the line of the axis that may be put upon the bearing. Or, if we divide 70,000 by the number of pounds per square inch of section, then the quotient will be the velocity in feet per minute at which the circumference of the bearing may work.

Q. The number of square inches upon which the pressure is reckoned is not the circumference of the bearing multiplied by its length, but the diameter of the bearing multiplied by its length?

A. Precisely so; it will be the diameter multiplied by the length of the bearing.

Q. What is the amount of friction in the case of surfaces sliding upon one another in sandy or muddy water--such surfaces, for example, as are to be found in the sluices of valves for water?

A. Various experiments have been made by Mr. Summers, of Southampton, to ascertain the friction of brass surfaces sliding upon each other in salt water, with the view of finding the power required for moving sluice doors, for lock-gates, and for other similar purposes. The surfaces were planed as true and smooth as the planing machine would make them, but were *not* filed or scraped, and the result was as follows:—

Area of rubbing Surface of Slide	Weight or pressure on rubbing Surface	Power required to move the Slide *slowly* in muddy Salt Water, kept stirred up
Sq. in.	lbs	lbs.
8	56	21·5
8	112	44·
8	168	65·5
8	224	88·5
8	336	140·5
8	448	170·75

These results were the average of eight fair trials : in each case the sliding surfaces were totally immersed in muddy salt-water,

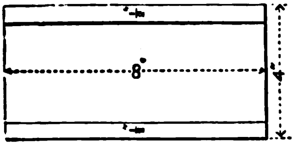

Fig. 29.—Sketch of Slide.

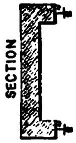

Fig. 30.

The facing on which the slide moved was similar, but three or four times as long.

and although the apparatus used for drawing the slide along was not very delicately fitted up, the power required may be considered as a sufficient approximation for practical purposes.

It appears from these experiments, that rough surfaces follow the same law as regards friction that is followed by smooth, for in each case the friction increases directly as the pressure.

STRENGTH OF MATERIALS AND OF MACHINES.

Q. In what way are the strengths of the different parts of a steam engine determined ?

A. By reference to the amount of the strain or pressure to which they are subjected, and to the cohesive strength of the iron or other material of which they are composed. The strains subsisting in engines are usually characterised as tensile, crushing, twisting, breaking, and shearing strains. But they may be all resolved into strains of extension and strains of compression ; and by the power of the materials to resist these two strains will their practical strength be measurable.

Q. What are the ultimate strengths of the malleable and cast iron, brass, and other materials employed in the construction of engines ?

A. The tensile and crushing strengths of any given material are by no means the same. The tensile strength, or strength when extended, of good bar iron is about 60,000 lbs., or nearly 27 tons per square inch of section ; and the tensile strength of cast iron is about 15,000 lbs., or say 6¾ to 7 tons per square inch of section. These are the weights which are required to break them. The crushing strength of cast iron, however, is about 100,000 lbs., or 44½ tons ;

whereas the crushing strength of malleable iron is not more than 27,000 lbs., or 12 tons, per square inch of section ; and, indeed, it is generally less than this. The ultimate tensile strength, therefore, of malleable iron is four times greater than that of cast iron, but the crushing strength of cast iron is between three and four times greater than that of wrought iron. It may be stated, in round numbers, that the tensile strength of malleable iron is twice greater than its crushing strength ; or, in other words, that it will take twice the strain to break a bar of malleable iron by drawing it asunder endways, than will cripple it by forcing it together endways like a pillar ; whereas a bar of cast iron will be drawn asunder with one-sixth of the force that will be required to break or cripple it when forced together endways like a pillar.

Q. What is the cohesive strength of steel ?

A. The ultimate tensile strength of good cast or blistered steel is about twice as great as that of wrought iron, being about 130,000 lbs. per square inch of section. The tensile strength of gun-metal, such as is used in engines, is about 36,000 lbs. per square inch of section ; of wrought copper about 33,000 lbs. ; and of cast copper about 19,000 lbs. per square inch of section. In extension, homogeneous metal is about as strong as steel.

Q. Is the crushing strength of steel greater or less than its tensile strength ?

A. It is about twice greater. A good steel punch will punch through a plate of wrought iron of a thickness equal to the diameter of the punch. Now it is well known that the strain required to punch a piece of metal out of a plate is just the same as that required to tear asunder a bar of iron of the same area of cross section as the area of the surface cut. The area of the surface cut in punching an inch plate will be the circumference of the punch, 3·1416 inches, multiplied by the thickness of the plate, 1 inch, which makes the area of the cut surface 3·1416 square inches. In other words, it will require four times the strain to crush steel that is required to tear asunder malleable iron, or it will take about twice the strain to crush steel that it will require to break it by extension. These conclusions are supported by the results of extensive experiments on the strength of steel, of which an account was presented to the British Association in 1867.

Q. What strain may be applied to malleable iron in practice ?

A. A bar of wrought iron to which a tensile or compressing strain is applied is elongated or contracted like a very stiff spiral spring, nearly in the proportion of the amount of strain applied up to the limit at which the strength begins to give way, and within this limit it will recover its original dimensions when the strain is removed. If, however, the strain be carried beyond this limit, the bar will not recover its original dimensions, but will be permanently pulled out or pushed in, just as would happen to a spring to which an undue strain had been applied. This limit is what is called the limit of elasticity; and whenever it is exceeded, the bar, though it may not break immediately, will undergo a progressive deterioration, and will break in the course of time. The limit of elasticity of malleable iron, when extended—or, in other words, the tensile strain to which a bar of malleable iron an inch square may be subjected without permanently deranging its structure—is usually taken at 17,800 lbs., or from that to 10 tons, depending on the quality of the iron. It has also been found that malleable iron is extended about one ten thousandth part of its length for every ton of direct strain applied to it.

Q. What is the limit of elasticity of cast iron?

A. It is commonly taken at 15,300 lbs. per square inch of section; but this is certainly much too high, as it exceeds the tensile strength of irons of medium quality. A bar of cast iron, if compressed by weights, will be contracted in length twice as much as a bar of malleable iron under similar circumstances; but malleable iron, when subjected to a greater strain than twelve tons per square inch of section, gradually crumples up by the mere continuance of the weight. A cast iron bar one inch square and ten feet long is shortened about one tenth of an inch by a compressing force of 10,000 lbs., whereas a malleable iron bar of the same dimensions would require to shorten it equally a compressing force of 20,000 lbs. As the load, however, approaches twelve tons, the compressions become nearly equal, and above that point the rate of the compression of the malleable iron rapidly increases. A bar of cast iron, when at its breaking point by the application of a tensile strain, is stretched about one six hundredth part of its length; and an equal strain employed to compress it would shorten it about one eight hundredth part of its length.

Q. But to what strain may the iron used in the construction of engines be safely subjected?

A. The most of the working parts of modern engines are made of wrought iron or steel, and the utmost strain to which wrought iron should be subjected in machinery is 4,000 lbs. per square inch of section. Cast iron should not be subjected to more than half of this. In locomotive boilers the strain of 4,000 lbs. per square inch of section is sometimes exceeded by one half or more ; but such an excess of strain approaches the limits of danger.

Q. Will you explain in what way the various strains subsisting in a steam engine may be resolved into tensile and crushing strains ; also in what way the magnitude of those strains may be determined ?

A. To take the case of a beam subjected to a transverse strain, such as the great beam of an engine, it is clear, if we suppose the beam broken through the middle, that the amount of strain at the upper and lower edges of the beam, where the whole strain may be supposed to be collected, will, with any given pressure on the piston, depend upon the proportion of the length to the depth of the beam. One edge of the beam breaks by extension, and the other edge by compression ; and the upper and lower edges may be regarded as pillars, one of which is extended by the strain, and the other is compressed. If, to make an extreme supposition, the depth of the beam is taken as equal to its length, then the pillars answering to the edges of the beam will be compressed, and extended by what is virtually a bell-crank lever with equal arms, the horizontal distance from the main centre to the end of the beam being one of the arms, and the vertical height from the main centre to the top edge of the beam being the other arm. The distance, therefore, passed through by the fractured edge of the beam during a stroke of the engine will be equal to the length of the stroke, and the strain it will have to sustain will consequently be equal to the pressure on the piston. If its motion were only half that of the piston, as would be the case if its depth were made one-half less, the strain the beam would have to bear would be twice as great ; and it may be set down as an axiom that the strain upon any part of a steam engine or other machine is inversely equal to the strain produced by the prime mover multiplied by the comparative velocity with which the part in question moves. If any part of an engine moves with less velocity than the piston, it will have a greater strain on it, if resisted, than is thrown upon the piston. If it moves with greater velocity than the piston, it will have a less strain upon it, and the difference of strain will in every case be in the inverse proportion of the difference of the velocity.

Q. Then in computing the amount of metal necessary to give due strength to a beam, the first point is to determine the velocity with which the edge of the beam moves at that point where the strain is greatest?

A. The web of a cast-iron beam or girder serves merely to connect the upper and lower edges or flanges rigidly together, so as to enable the extending and compressing strains to be counteracted in an effectual manner by the metal of those flanges. It is only necessary, therefore, to make the flanges of sufficient strength to resist effectually the crushing and tensile strains to which they are exposed, and to make the web of the beam of sufficient strength to prevent a distortion of its shape from taking place.

Q. Is the strain greater from being movable or intermittent than if it was stationary?

A. Yes; it is nearly twice as great from being movable. Engineers are in the habit of making girders intended to sustain a stationary load about three times stronger than the breaking weight; but if the load be a movable one, as is the case in the girders of railway bridges, they make the strength equal to six times the breaking weight.

Q. Then the strain is increased by the suddenness with which it is applied?

A. If a weight be placed on a long and slender beam propped up in the middle, and the prop be suddenly withdrawn, so as to allow deflection to take place, it is clear that the deflection must be greater than if the load had been gradually applied. The momentum of the weight, and also of the beam itself, falling through the space through which it has been deflected has necessarily to be counteracted by the elasticity of the beam, and the beam will therefore be momentarily bent to a greater extent than what is due to the load, and after a few vibrations up and down it will finally settle at that point of deflection which the load properly occasions. It is obvious that such a beam must be strong enough, not merely to sustain the pressure due to the load, but also that accession of pressure due to the counteracted momentum of the weight and of the beam itself. Although in steam engines the beam is not loaded by a weight, but by the pressure of the steam, yet the momentum of the beam itself must in every case be counteracted, and the momentum will be considerable in every case in which a large and rapid deflection takes place. A rapid deflection increases the amount of the deflection as well as the amount of the strain, as is seen in the cylinder cover of a Cornish pumping-engine, into which the steam is suddenly admitted, and in which the momentum of the particles of the metal put into motion increases the deflection to an extent such as the mere pressure of the steam could not produce.

Q. What will be the amount of increased strain consequent upon deflection?

A. The momentum of any moving body being proportional to the square of its velocity, it follows that the strain will be proportional to the square of the amount of deflection produced in a specified time.

Q. But will not the inertia of a beam resist deflection, as well as the momentum increase deflection?

A. No doubt that will be so; but whether in practical cases increase of mass without reference to strength or load will, upon the whole, increase or diminish deflection will depend very much upon the magnitude of the mass relatively with the magnitude of the deflecting pressure, and the rapidity with which that pressure is applied and removed. Thus, if a force or weight be very suddenly applied to the middle of a ponderous beam, and be as suddenly withdrawn, the inertia of the beam will, as in the case of the collision of bodies, tend to resist the force, and thus obviate deflection to a considerable extent; but if the pressure be so long continued as to produce the amount of deflection due to the pressure, the effect of the inertia in that case will be to increase the deflection.

Q. Will the pressure given to the beam of an engine alternately in opposite directions facilitate its fracture?

A. Iron beams, bent alternately in opposite directions, or alternately deflected and released, will be broken in the course of time with a much less strain than is necessary to produce immediate fracture. It has been found, experimentally, that a cast-iron bar deflected by a revolving cam to only half the extent due to its breaking weight will in no case withstand 900 successive deflections; but, if bent by the cam to only one-third of its ultimate deflection, it will withstand 100,000 deflections without visible injury. Looking, however, to the jolts and vibrations to which engines are subject, and the sudden strains sometimes thrown upon them, either from water getting into the cylinder or otherwise, it does not appear that a strength answering to six times the breaking weight will give sufficient margin for safety in the case of cast-iron engine beams.

Q. Does the same law hold in the case of the deflection of malleable iron bars?

A. In the case of malleable iron bars it has been found that no very perceptible damage was caused by 10,000 deflections, each deflection being such as was due to half the load that produced a large permanent deflection.

Q. The power of a rod or pillar to resist compression becomes very little when the diameter is small and the length great?

A. The power of a rod or pillar to resist compression varies nearly as the fourth power of the diameter divided by the square of the length. In the case of hollow cylindrical columns of cast iron, it has been found, experimentally, that the 3·55th power of the internal diameter, subtracted from the 3·55th power of the external diameter, and divided by the 1·7th power of the length, will represent the strength very nearly. In the case of hollow cylindrical columns of malleable iron, experiment shows that the 3·59th power of the internal diameter, subtracted from the 3·59th power of the external diameter, and divided by the square of the length, gives a proper expression for the strength; but this rule only holds where the strain does not exceed eight or nine tons on the square inch of section. Beyond twelve or thirteen tons per square inch of section, the metal cannot be depended upon to withstand the strain, though hollow pillars will sometimes bear fifteen or sixteen tons per square inch of section.

Q. Does not the thickness of the metal of the pillars or tubes affect the question?

A. It manifestly does; for a tube of very thin metal, such as gold-leaf or tin-foil, would not stand on end at all, being crushed down by its own weight. It is found, experimentally, that in malleable iron tubes of the respective thicknesses of ·525, ·272, and ·124 inches, the resistances to crushing per square inch of section are 19·17, 14·47, and 7·47 tons respectively. The power of plates to resist compression varies nearly as the cube, or, more nearly, as the 2·878th power of their thickness; but this law only holds so long as the pressure applied does not exceed from nine to twelve tons per square inch of section. When the pressure is greater than this, the metal is crushed, and a new law supervenes.

Q. In a riveted tube, will the riveting be much damaged by heavy strains?

A. It will be most affected by percussion. Long-continued impact on the side of a tube, producing a deflection of only one-fifth of that which would be required to injure it by pressure, is found to be destructive of the riveting; but in large riveted structures, such as a ship or a railway bridge, the inertia of the mass will by resisting the effect of impact, prevent any injurious action from this cause from taking place.

Q. Will the power of iron to resist shocks be in all cases proportional to its power to resist strains?

A. By no means. Some cast iron is very hard and brittle; and although it will in this state resist compression very strongly, it will be easily broken by a blow. Iron which has been re-melted many times generally falls into this category, as it will also do if run into very small castings. It has been found, by experiment, that iron, of which the crushing strength per square inch is about 42 tons, will, if remelted twelve times, bear a crushing weight of 70 tons, and if re-melted eighteen times, it will bear a crushing weight of 83 tons; but, taking its power to resist impact in its first state at 706, this power will be raised at the twelfth re-melting to 1,153, and will be sunk at the eighteenth re-melting to 149.

Q. From all this it appears that a combination of cast iron and malleable iron is the best for the beams of engines?

A. Yes, and for all beams. Engine beams should be made deeper at the middle than they are now made: the web should be lightened by holes pierced in it, and round the edge of the beam there should be a malleable iron hoop or strap applied, as is done in the case of American engine beams. The flanges at the edges of engine beams are invariably made too small. It is in them that the strength of the beam chiefly resides. In wrought-iron girders the area of the section of the top flange should be somewhat greater than that of the bottom one. In steel girders the bottom flange should be twice the area of the top flange, and in cast-iron girders the bottom flange should be six times the area of the top flange.

HEAT.

Q. What is meant by latent heat?

A. By latent heat is meant the heat existing in bodies which is not discoverable by the touch or by the thermometer, but which manifests its existence by producing a change of state. Heat is absorbed in the liquefaction of ice, and in the vaporisation of water, yet the temperature does not rise during either process, and the heat absorbed is therefore said to become latent. The term is somewhat objectionable, as the effect proper to the absorption of heat has in each case been made visible; and it would be as reasonable to call hot water latent steam. Latent heat, in the present acceptation of the term, means sensible liquefaction or vaporisation; but to produce these changes heat is as necessary as to produce the expansion of mercury in a thermometer tube, which is taken as the measure of temperature; and it is hard to see on what ground heat can be said to be latent when its presence is made manifest by changes which only heat can effect. It is the *temperature* only that is latent, and latent temperature means sensible vaporisation or liquefaction.

Q. But when you talk of the latent heat of steam, what do you mean to express?

A. I mean to express the heat consumed in accomplishing the vaporisation compared with that necessary for producing the temperature. The latent heat of steam is usually reckoned at about 1,000 degrees, by which it is meant that there is as much heat in any given weight of steam as would raise its constituent water 1,000 degrees if the expansion of the water could be prevented, or as would raise 1,000 times that quantity of water 1 degree. The boiling-point of water, being 212 degrees, is 180 degrees above the freezing-point of water—the freezing-point being 32 degrees; so that it requires 1,180 times as much heat to raise 1 lb. of water into steam, as to raise 1 lb. of water 1 degree; or it requires about as much heat to raise 1 lb. of boiling water into steam as would raise 5½ lbs. of water from the freezing to the boiling point, 5½ multiplied by 180 being 990, or 1,000 nearly.

Q. When it is stated that the latent heat of steam is 1,000 degrees, it is only meant that this is a rough approximation to the truth?

A. Precisely so. The latent heat, in point of fact, is not uniform at all temperatures; neither is the total amount of heat the same at all temperatures. M. Regnault has shown, by a very elaborate series of experiments, that the total heat in steam increases somewhat with the pressure, and that the latent heat diminishes somewhat with the pressure. This will be made obvious by the following numbers:—

Pressure	Temperature	Total Heat	Latent Heat
lbs.	Degrees	Degrees	Degrees
15	213·1	1178·9	965·8
50	281·0	1199·6	918·6
100	327·8	1213·9	886·1

If, then, steam of 100 lbs. be expanded down to steam of 15 lbs., it will have 35 degrees of heat over that which is required for the maintenance of the vaporous state, or, in other words, it will be surcharged with heat.

Q. What do you understand by specific heat?

A. By specific heat I understand the relative quantities of heat in bodies at the same temperature, just as by specific gravity I understand the relative quantities of matter in bodies of the same bulk. Equal weights of quicksilver and water at the same temperature do not contain the same quantities of heat any more than equal bulks of those liquids contain the same quantity of matter. The absolute quantity of heat in any body is not known; but the relative heat of bodies at the same temperature, or, in other words, their specific heats, have been ascertained and arranged in tables—the specific heat of water being taken as unity.

Q. In what way does the specific heat of a body enable the quantity of heat in it to be determined?

A. If any body has only half the specific heat of water, then a pound of that body will, at any given temperature, have only half the heat in it that is in a pound of water at the same temperature. The specific heat of air is ·2377, that of water being 1; or it is 4·207 times less than that of water. An amount of heat, therefore, which would raise a pound of water 1 degree would raise a pound of air 4·207 degrees.

Q. What is the amount of power which a given quantity of heat produces in the best existing engines as compared with what it should produce in a perfect engine?

A. About one-tenth. It has already been explained that a pound of water raised 1 degree in temperature is what is called a thermal unit, by which any quantity of heat above the atmospheric temperature is measurable, and the heat consumed by an engine can be measured by this unit so as to determine its precise amount. The mechanical equivalent of a thermal unit being 772 lbs. lifted through 1 foot, this amount of power is what is termed the mechanical equivalent of heat. It is found that the most perfect modern engines, when examined by the aid of this test, do not convert more than about one-tenth of the heat into power, the rest going off as waste steam or hot water.

Q. What is the main cause of this great waste, and how is it to be prevented?

A. The main cause is taking the temperature of the steam as the starting-point, instead of the temperature of the furnace. The temperature of the steam may be 300° Fahr., whereas the temperature of the furnace is 3,000° Fahr. or more ; and if steam or some other fluid were to be taken at a temperature of 3,000°, and the temperature reduced to 300° by expansion, generating power all the way, it is clear that much power would be recovered that is at present wasted. No doubt, in steam boilers communicating heat through metallic surfaces, it is necessary to have a large difference in the temperature of the water and of the furnace, else conduction could not go on. But this is only another way of saying that the existing arrangement is very imperfect, as the heat may be imparted by jet, like the cold in jet condensers. It is in this direction that the road lies to the establishment of improved methods for producing motive power.

COMBUSTION.

Q. What is the nature of combustion ?

A. Combustion is nothing more than an energetic chemical combination, or, in other words, it is the mutual neutralisation of opposing electricities. When coal is brought to a high temperature it acquires a strong affinity for oxygen, and combination with oxygen will produce more than sufficient heat to maintain the original temperature ; so that part of the heat is rendered applicable to other purposes.

Q. Does air consist of oxygen ?

A. Air consists of oxygen and nitrogen mixed together in the proportion of 3·29 lbs. of nitrogen to 1 lb. of oxygen. Every pound of coal requires about 2·66 lbs. of oxygen for its saturation, and therefore for every pound of coal burned 8·75 lbs. of nitrogen must pass through the fire, supposing all the oxygen to enter into combination. In practice, however, this perfection of combination does not exist : from one-third to one-half of the oxygen will pass through the fire without entering into combination at all ; so that from 16 to 18 lbs. of air are required for every pound of coal burned. 18 lbs. of air are about 240 cubic feet, which may be taken as the quantity of air required for the combustion of a pound of coal in practice.

Q. What are the constituents of coal ?

A. The chief constituent of coal is carbon or pure charcoal, which is associated in various proportions with volatile and earthy matters. English coal contains 80 to 90 per cent. of carbon, and from 8 to 18 per cent. volatile and earthy matters, but sometimes more than this. The volatile matters are hydrogen, nitrogen, oxygen, and sulphur.

Q. What is the difference between anthracite and bituminous coal?

A. Anthracite consists almost entirely of carbon, having 91 per cent. of carbon, with about 7 per cent. of volatile matter and 2 per cent. of ashes. Newcastle coal contains about 83 per cent. of carbon, 14 per cent. of volatile matter, and 3 per cent of ashes.

Q. Will you recapitulate the steps by which you determine the quantity of air required for the combustion of coal?

A. Looking to the quantity of oxygen required to unite chemically with the various constituents of the coal, we find, for example that in 100 lbs. of anthracite coal consisting of 91·44 lbs. of carbon and 3·46 lbs. of hydrogen we shall for the 91·44 lbs. of carbon require 243·84 lbs. of oxygen—since to saturate a pound of carbon by the formation of carbonic acid requires 2⅔ lbs. of oxygen. To saturate a pound of hydrogen in the formation of water requires 8 lbs. of oxygen; hence 3·46 lbs. of hydrogen will take 27·68 lbs. of oxygen for its saturation. If, then, we add 243·84 lbs. to 27·68 lbs., we have 271·52 lbs. of oxygen required for the combustion of 100 lbs. of coal. A given weight of air contains nearly 23·32 per cent. of oxygen; hence, to obtain 271·52 lbs. of oxygen, we must have about four times that quantity of atmospheric air, or, more accurately, 1,164 lbs. of air for the combustion of 100 lbs. of coal. A cubic foot of air at ordinary temperatures weighs about ·075 lbs.; so that 100 lbs. of coal require 15,524 cubic feet of air, or 1 lb. of coal requires about 155 cubic feet of air, supposing every atom of the oxygen to enter into combination. If, then, from one-third to one-half of the air passes unconsumed through the fire, an allowance of 240 cubic feet of air for each pound of coal will be a small enough allowance to answer the requirements of practice, and in some cases as much as 320 cubic feet will be required—the difference depending mainly on the peculiar configuration of the furnace.

Q. Can you state the evaporative efficacy of a pound of coal?

A. The evaporative efficacy of a pound of carbon has been found experimentally to be equivalent to that necessary to raise 14,000 lbs. of water through 1 degree, or 14 lbs. of water through 1,000 degrees, supposing the whole heat generated to be absorbed by the water. Now, if the water be raised into steam from a temperature of 60°, then 1118·9° of heat will have to be imparted to it to convert it into steam of 15 lbs. pressure per square inch. 14,000÷1118·9=12·512 lbs. will be the number of pounds of water, therefore, which a pound of carbon can raise into steam of 15 lbs. pressure from a temperature of 60°. This, however, is a laboratory result, and is a considerably larger result than can be expected in practice.

Q. Then what is the result that may be expected in practice?

A. The evaporative powers of different coals appear to be nearly proportional to the quantity of carbon in them; and bituminous coal is, therefore, less efficacious than coal consisting chiefly of pure carbon. A pound of the best Welsh or anthracite coal is capable of raising from 9½ to 10 lbs. of water from 212° into steam, whereas a pound of the best Newcastle is not capable of raising more than about 8½ lbs. of water from 212° into steam; and inferior coals will not raise more than 6½ lbs. of water into steam. In America it has been found that 1 lb. of the best coal is equal to 2½ lbs. of pine wood, or, in some cases, to 3 lbs.; and a pound of pine wood will not usually evaporate more than about 2½ lbs. of water, though, by careful management, it may be made to evaporate 4½ lbs. Turf will generate rather more steam than wood. Coke is equal or somewhat superior to the best coal in evaporative effect.

Q. How much water will a pound of coal raise into steam in ordinary boilers?

A. From 6 to 8 lbs. of water in the generality of land boilers of medium quality, the difference depending on the kind of boiler, the kind of coal, and other circumstances. Mr. Watt reckoned his boilers as capable of evaporating 10·08 cubic feet of water with a bushel, or 84 lbs., of Newcastle coal, which is equivalent to 7½ lbs. of water evaporated by 1 lb. of coal; and this may be taken as the performance of common land boilers at the present time. In some of the Cornish boilers, however, a pound of coal raises 11·8 lbs. of boiling water into steam, or a hundredweight of coal evaporates about 21 cubic feet of water from 212°.

Q. What method of firing ordinary furnaces is the best?

A. The coals should be broken up into small pieces, and sprinkled thinly and evenly over the fire a little at a time. The thickness of the stratum of coal upon the grate should depend upon the intensity of the draught. In ordinary land or marine boilers it should be thin, whereas in locomotive boilers it requires to be much thicker. If the stratum of coal be thick while the draught is sluggish, the carbonic acid resulting from combustion combines with an additional atom of carbon in passing through the fire, and is converted into carbonic oxide, which may be defined to be invisible smoke, as it carries off a portion of the fuel : if, on the contrary, the stratum of coal be thin while the draught is very rapid, an injurious refrigeration is occasioned by the excess of air passing through the furnace. The fire should always be spread of uniform thickness over the bars of the grate, and should be without any holes or uncovered places, which greatly diminish the effect of the fuel by the refrigeratory action of the stream of cold air which enters thereby. A wood fire requires to be about six inches thicker than a coal one, and the wood should be cut into short billets. A turf fire requires to be three or four inches thicker than a wood one, so that the furnace bars must be placed lower where wood or turf is burned to enable the surface of the fire to be at the same distance from the bottom of the boiler.

Q. Is a slow or a rapid combustion the most beneficial?

A. A slow combustion is found by experiment to give the best results as regards economy of fuel, and theory tells us that the largest advantage will necessarily be obtained where adequate time has been afforded for a complete combination of the constituent atoms of the combustible and the supporter of combustion, and ample surface for the absorption of the heat. In many of the cases, however, which occur in practice, a slow combustion is not attainable; but the tendencies of slow combustion are both to save the fuel and to burn the smoke.

Q. Is not the combustion in the furnaces of the Cornish boilers very slow?

A. Yes, very slow ; and there is in consequence very little smoke evolved. The coal used in Cornwall is Welsh coal, which generates but little smoke, and is therefore more favourable for the success of a smokeless furnace ; but in the manufacturing districts where the coal is more bituminous, it is found that smoke may be almost wholly prevented by careful firing, and by the use of a large capacity of furnace.

Q. Do you consider slow combustion to be an advisable thing to practise in steam vessels?

A. No, I do not. When the combustion is slow the heat in the furnaces and flues is less intense, and a larger amount of heating surface consequently becomes necessary to absorb the heat. In locomotives, where the heat of the furnace is very intense, there will be the same economy of fuel with an allowance of five or six square feet of surface to evaporate a cubic foot of water as in common marine boilers with ten or twelve.

Q. What is the method of consuming smoke pursued in the manufacturing districts?

A. In Manchester, where some stringent regulations for the prevention of smoke have for some time been in force, it is found that the readiest way of burning the smoke is to have a very large proportion of furnace room, whereby slow combustion may be carried on. In some cases, too, a favourable result is arrived at by raising a ridge of coal across the furnace lying against the bridge, and of the same height. This ridge speedily becomes a mass of incandescent coke, which promotes the combustion of the smoke passing over it.

Q. Is the method of admitting a stream of air into the flues to burn the smoke regarded favourably?

A. No; it is found to be productive of injury to the boiler by the violent alternations of temperature it occasions, as at some times cold air impinges on the iron of the boiler, and at other times flame, just as there happens to be smoke or no smoke emitted by the furnace. Boilers, therefore, operating upon this principle speedily become leaky, and are much worn by oxidation. It is very difficult to apportion the quantity of air admitted to the varying wants of the fire; and as air may at some times be rushing in when there is no smoke to consume, a loss of heat and an increased consumption of fuel may be the result of the arrangement; and, indeed, such is the result in practice, though a carefully performed experiment usually demonstrates a saving in fuel of ten or twelve per cent.

Q. What other plans have been contrived for obviating the nuisance of smoke?

A. They are too various for enumeration, but most of them either operate upon the principle of admitting air into the flues to accomplish the combustion of the uninflammable parts of the smoke, or seek to attain the same object by passing the smoke over or through the fire or other incandescent material. Some of the plans, indeed, profess to burn the inflammable gases as they are evolved from the coal, without permitting the admixture of any of the uninflammable products of combustion which enter into the composition of smoke; but this object has been very imperfectly fulfilled in any of the contrivances yet brought under the notice of the public, and in some cases these contrivances have been found to create weightier evils than they professed to relieve.

Q. Had Mr. Watt any method of consuming smoke?

A. He tried various methods, but eventually fixed upon the method of coking the coal on a dead plate at the furnace door before pushing it into the fire. That method is perfectly effectual where the combustion is so slow that the requisite time for coking is allowed, and it is much preferable to any of the methods of admitting air at the bridge or elsewhere to accomplish the combustion of the inflammable parts of the smoke.

Q. What are the details of Mr. Watt's arrangement as now employed?

A. The fire bars and the dead plate are both set at a considerable inclination to facilitate the advance of the fuel into the furnace. In Boulton and Watt's 30-horse-power land boiler the dead plate and the furnace bars are each about four feet long, and they are set at the angle of 30 degrees with the horizon.

Q. Is the use of the dead plate universally adopted in Boulton and Watt's land boilers?

A. It is generally adopted, but in some cases Boulton and Watt have substituted the plan of a revolving grate for consuming the smoke, and the dead plate then becomes both superfluous and inapplicable. In this contrivance the fire is replenished with coals by a self-acting mechanism.

Q. Will you explain the arrangement of the revolving grate?

A. The fire grate is made like a round table capable of turning horizontally upon a centre; a shower of coal is precipitated upon the grate through a slit in the boiler near the furnace mouth, and the smoke evolved from the coal dropped at the front part of the fire is consumed by passing over the incandescent fuel at the back part, from which all the smoke must have been expelled in the revolution of the grate before it can have reached that position.

Q. Is a self-feeding furnace applicable to a steam vessel?

A. I see nothing to prevent its application, nor, indeed, is it improbable that gas furnaces like those now used for metallurgic purposes will be introduced. The introduction of any effectual automatic contrivance for feeding the fire in steam vessels would bring about an important economy in labour at the same time that it would give the assurance of the work being better done. It is very difficult to fire furnaces by hand effectually at sea, especially in rough weather and in tropical climates, whereas machinery would be unaffected by any such disturbing causes, and would perform with little expense the work of many men; or if the fuel be turned into carbonic oxide, it may obviously all be burned as gas.

Q. Have any other plans been devised for feeding the fire by self-acting means besides that of a revolving grate?

A. Yes, many plans; but none of them, perhaps, are free from an objectionable complication. In some arrangements the bars are made like screws, which, being turned round slowly, gradually carry forward the coal, while in other arrangements the same object is sought to be attained by alternately lifting and depressing every second bar at the end nearest the mouth of the furnace. In Juckes' furnace, represented in fig. 31, the fire-bars are arranged in the manner of rows of endless chains working over a roller at the mouth of the furnace, and another roller at the further end of the furnace. These rollers are put into slow revolution, and the coal which is deposited at the mouth of the furnace is gradually carried forward by the motion of the chains, which act like an endless web. The clinkers and ashes left after the combustion of the coal are precipitated into the ash-pit, where the chain turns down over the roller at the extremity of the furnace.

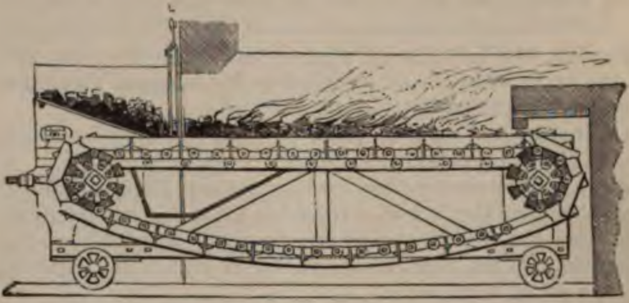

Fig. 31.—Juckes' Patent Furnace.

Q. Have not many plans been contrived which consume the smoke of furnaces very effectually?

A. Yes, many plans; and besides those already mentioned, there are Hall's, Coupland's, Godson's, Robinson's, Stevens's, Hazeldine's, Inche's, Bristow and Attwood's, and a great number of others. One plan consists in making the flame descend through

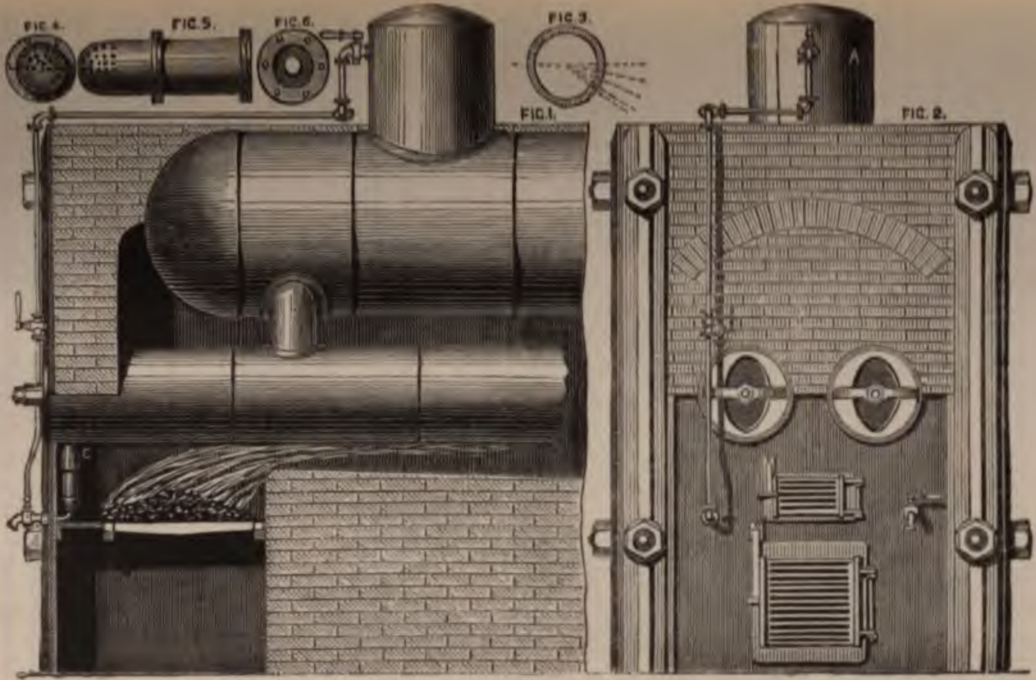

Fig. 32.—Thierry's Smoke-Consuming Furnace,

the fire-bars, and the fire-bars are formed of tubes set on an incline and filled with water, which water will circulate with a rapidity proportionate to the intensity of the heat. In Thierry's plan for consuming smoke, shown in operation at the Paris Exhibition of 1867, and of which a representation is given in fig. 32 (details in sub-figs. 1 to 6) a number of jets of highly superheated steam are directed obliquely upon the fire from a pipe which runs across the front of the furnace within and above the furnace door. On the whole, gas furnaces promise best.

STEAM.

Q. Have experiments been made to determine the elasticity of steam at different temperatures?

A. Yes; very careful experiments. The following rule expresses the results obtained by Mr. Southern:—To the given temperature in degrees of Fahrenheit add 51·3 degrees: from the logarithm of the sum subtract the logarithm of 135·767, which is 2·1327940; multiply the remainder by 5·13, and to the natural number answering to the sum add the constant fraction ·1, which will give the elastic force in inches of mercury. If the elastic force be known, and it is wanted to determine the corresponding temperature, the rule must be modified, thus:—From the elastic force, in inches of mercury, subtract the decimal ·1, divide the logarithm of the remainder by 5·13, and to the quotient add the logarithm 2·1327940; find the natural number answering to the sum, and subtract therefrom the constant 51·3; the remainder will be the temperature sought. The French Academy and the Franklin Institute have repeated Mr. Southern's experiments on a larger scale. The results obtained by them are not widely different, and are, perhaps, nearer the truth; but Mr. Southern's results are generally adopted by engineers as sufficiently accurate for practical purposes.

Q. Have not more recent experiments upon this subject been made in France by M. Regnault?

A. Yes; the experiments of M. Regnault upon this subject have been very elaborate and very carefully conducted, and the results are probably more accurate than have been heretofore obtained. Nevertheless, it is questionable how far it is advisable to disturb the rules of Watt and Southern, with which the practice of engineers is very much identified, for the sake of emendations which are not of such magnitude as to influence materially the practical result. M. Regnault has shown that the total amount of heat existing in a given weight of steam increases slightly with the pressure, so that the sum of the latent and sensible heats do not precisely form a constant quantity. Thus, in steam of the atmospheric pressure, or with 14·7 lbs. upon the square inch, the sensible heat of the steam is 212 degrees, the latent heat 966·6 degrees, and the sum of the latent and sensible heats 1178·6 degrees; whereas in steam of 90 lbs. upon the square inch the sensible heat is 320·2 degrees, the latent heat 891·4 degrees, and the sum of the latent and sensible heats 1211·0 degrees. There is, therefore, 33 degrees less of heat in any given weight of water, raised into steam of the atmospheric pressure, than if raised into steam of 90 lbs. pressure.

Q. What expansion does water undergo in its conversion into steam?

A. A cubic inch of water makes about a cubic foot of steam of the atmospheric pressure.

Q. And how much at a higher pressure?

A. That depends upon what the pressure is. But the proportion is easily ascertained, for the pressure and the bulk of a given quantity of steam, as of air or any other elastic fluid, are always inversely proportional to one another. Thus, if a cubic inch of water makes a cubic foot of steam with the pressure of one atmosphere, it will make half a cubic foot with the pressure of two atmospheres, a third of a cubic foot with the pressure of three atmospheres, and so on in all other proportions. High pressure steam, indeed, is just low pressure steam forced into a less space, and the pressure will always be great in the proportion in which the space is contracted.

Q. If this be so, the quantity of heat in a given weight of steam must be nearly the same, whether the steam is high or low pressure?

A. Yes; the heat in steam is nearly a constant quantity at all pressures, but not so precisely. Steam to which an additional quantity of heat has been imparted after leaving the boiler, or as it is called 'superheated steam,' comes under a different law, for the elasticity of such steam may be increased without any addition being made to its weight; but with the amount of superheating at present employed for working engines, it may be considered in practice that a pound of steam contains very nearly the same quantity of heat at all pressures.

Q. Does not the quantity of heat in any body vary with the temperature?

A. Other circumstances remaining the same, the quantity of heat in a body increases with the temperature.

Q. And is not high pressure steam hotter than low pressure steam?

A. Yes, the temperature of steam rises with the pressure.

Q. How then comes it that there is the same quantity of heat in the same weight of high and low pressure steam, when the high pressure steam has the highest temperature?

A. Because, although the temperature or sensible heat rises with the pressure, the latent heat becomes less in about the same proportion; and, as has been already explained, the latent and sensible heats taken together make up nearly the same amount at all temperatures. But the amount is somewhat greater at the higher temperatures. As a damp sponge becomes wet when subjected to pressure, so warm vapour becomes hot when forced into less bulk, but in neither case does the quantity of moisture or the quantity of heat sustain any alteration. Common air becomes so hot by compression that tinder may be inflamed by it, as is seen in the instrument for producing instantaneous light by suddenly forcing air into a syringe.

Q. What law is followed by superheated or surcharged steam on the application of heat?

A. The same as that followed by air, in which the increments in volume are very nearly in the same proportion as the increments in temperature; and the increment in volume for each degree of increased temperature is $\frac{1}{490}$th part of the volume at 32°. A volume of air which, at the temperature of 32°, occupies 100 cubic feet, will at 212° fill a space of 136·73 cubic feet. The volume which air or steam—out of contact with water—of a given temperature acquires by being heated to a higher temperature, the pressure remaining the same, may be found by the following rule:—To each of the temperatures, before and after expansion, add the constant number 459: divide the greater sum by the less, and multiply the quotient by the volume at the lower temperature: the product will give the expanded volume.

Q. If the relative volumes of steam and water are known, is it possible to tell the quantity of water which should be supplied to a boiler when the quantity of steam expended is specified?

A. Yes; at the atmospheric pressure about a cubic inch of water has to be supplied to the boiler for every cubic foot of steam abstracted; at other pressures, the relative bulk of water and steam may be determined as follows:—To the temperature of steam in degrees of Fahrenheit, add the constant number 459, multiply the sum by 37·3, and divide the product by the elastic force of the steam in pounds per square inch; the quotient will give the volume required.

Q. Will this rule give the proper dimensions of the pump for feeding the boiler with water?

A. No; it is necessary in practice that the feed pump should be able to supply the boiler with a much larger quantity of water than what is indicated by these proportions, from the risk of leaks, priming, or other disarrangements, and the feed pump is usually made capable of raising 3½ times the water evaporated by the boiler. About $\frac{1}{240}$th of the capacity of the cylinder answers very well for the capacity of the feed pump in the case of low-pressure engines, supposing the cylinder to be double-acting and the pump single-acting; but it is better to exceed this size.

Q. Is this rule for the size of the feed pump applicable to the case of high-pressure engines?

A. Clearly not; for since a cylinder full of high-pressure steam contains more water than the same cylinder full of low-pressure steam, the size of the pump must vary in the same proportion as the density of the steam. In all pumps a good deal of the effect is lost from the imperfect action of the valves; and in engines travelling at a high rate of speed, in particular, a large part of the water is apt to return through the suction-valve of the pump, especially if much lift be permitted to that valve. In steam vessels, moreover, when the boiler is fed with salt water, and where a certain quantity of supersalted water has to be blown out of the boiler from time to time to prevent the water from reaching too high a degree of concentration, the feed pump requires to be of additional size to supply the extra quantity of water thus rendered necessary. When the feed water is boiling or very hot, as in some engines is the case, the feed pump will not draw from a depth, and will altogether act less efficiently, so that an extra size of pump has to be provided in consequence. These and other considerations which might be mentioned show the propriety of making the feed pump very much larger than theory requires. The proper proportions of pumps, however, forms part of one of the succeeding chapters.

WORKING ENGINES EXPANSIVELY.

Q. What is meant by working engines expansively?

A. Adjusting the valves, so that the steam is shut off from the cylinder before the end of the stroke, whereby the residue of the stroke is left to be completed by the expanding steam.

Q. And what is the benefit of that practice?

A. It accomplishes an important saving of steam, or, what is the same thing, of fuel; but it diminishes the power of the engine, while increasing the power of the steam. A larger engine will be required to do the same work, but the work will be done with a smaller consumption of fuel. If, for example, the steam be shut off when only half the stroke is completed, there will only be half the quantity of steam used. But there will be more than half the power exerted; for although the pressure of the steam decreases after the supply entering from the boiler is shut off, yet it imparts, during its expansion, *some* power, and that power, it is clear, is obtained without any expenditure of steam or fuel whatever.

Q. What will be the pressure of the steam, under such circumstances, at the end of the stroke?

A. If the steam be shut off at half-stroke, the pressure of the steam, reckoning the total pressure both below and above the atmosphere, will just be one-half of what it was at the beginning of the stroke. It is a well-known law of pneumatics that the pressure of elastic fluids varies inversely as the spaces into which they are expanded or compressed. For example, if a cubic foot of air of the atmospheric density be compressed into the compass of half a cubic foot, its elasticity will be increased from 15 lbs. on the square inch to 30 lbs. on the square inch; whereas, if its volume be enlarged to two cubic feet, its elasticity will be reduced to 7½ lbs. on the square inch, being just half its original pressure. The same law holds in all other proportions, and with all other gases and vapours, provided their temperature remains unchanged; and if the steam valve of an engine be closed, when the piston has descended through one-fourth of the stroke, the steam within the cylinder will, at the end of the stroke, just exert one-fourth of its initial pressure.

Q. Then by computing the varying pressure at a number of stages, the average or mean pressure throughout the stroke may be approximately determined?

A. Precisely so. Thus, in the accompanying figure (fig. 33), let E be a cylinder, J the piston, *a* the steam pipe, *c* the upper port, *f* the lower port, *d* the steam pipe, prolonged to *e* the equilibrium valve, *g* the eduction valve, M the steam jacket, N the cylinder cover, O stuffing box, *n* piston rod, P cylinder bottom; let the cylinder be supposed to be divided in the direction of its length into any number of equal parts, say twenty, and let the diameter of the cylinder represent the pressure of the steam, which, for the sake of simplicity, we may take at 10 lbs., so that we may divide the cylinder in the direction of its diameter into ten equal parts. If, now, the piston be supposed to descend through five of the divisions, and the steam valve then be shut, the pressure at each subsequent position of the piston will be represented by a series, computed according to the laws of pneumatics, and which, if the initial pressure be represented by 1, will give a pressure of ·5 at the middle of the stroke, and ·25 at the end of it. If this series be set off on the horizontal lines, it will mark out a hyperbolic curve—the area of the part exterior to which represents the total efficacy of the stroke, and the interior area, therefore, represents the diminution in the power of a stroke when the steam is cut off at one-fourth of the descent. If the squares above the point where the

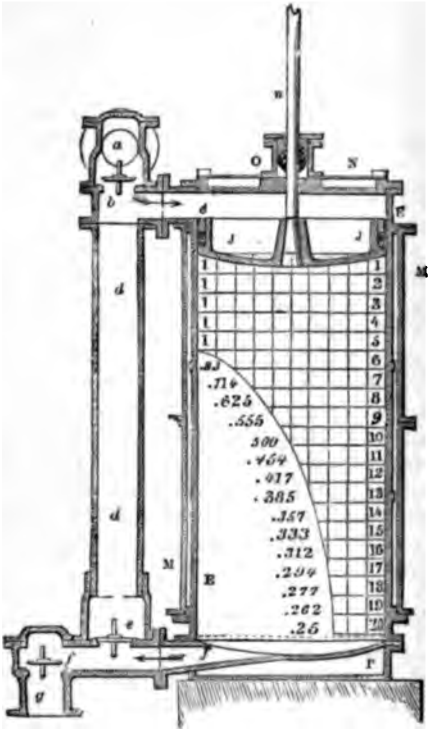

Fig. 33. - Diagram showing law of expansion of steam in a cylinder.

steam is cut off be counted, they will be found to amount to 50; and if those beneath that point be counted or estimated, they will be found to amount to about 69. These squares are representative of the power exerted; so that, while an amount of power represented by 50 has been obtained by the expenditure of a quarter of a cylinder full of steam, we get an amount of power represented by 69 without any expenditure of steam at all, merely by permitting the steam first used to expand into four times its original volume.

Q. Then, by working an engine expansively, the power of the steam is increased, but the power of the engine is diminished?

A. Yes. The efficacy of a given quantity of steam is more than doubled by expanding the steam four times, while the efficacy of each stroke is made nearly one half less. And, therefore, to carry out the expansive principle in practice, the cylinder requires to be larger than usual, or the piston faster than usual, in the proportion in which the expansion is carried out. Everyone who is acquainted with simple arithmetic can compute the terminal pressure of steam in a cylinder when he knows the initial pressure and the point at which the steam is cut off; and he can also find by the same process any pressure intermediate between the first and last. By setting down these pressures in a table, and taking their mean, he can determine the effect, with tolerable accuracy, of any particular measure of expansion. It is necessary to remark that it is tho total pressure of the steam that he must take; not the pressure above the atmosphere, but the pressure above a perfect vacuum.

Q. Can you give any rule for ascertaining at one operation the amount of benefit derivable from expansion?

A. Divide the length of the stroke through which the steam expands, by the length of stroke performed with full pressure, which last call 1; the hyperbolic logarithm of the quotient is the increase of efficiency due to expansion. According to this rule it will be found, that if a given quantity of steam, the power of which working at full pressure is represented by 1, be admitted into a cylinder of such a size that its ingress is concluded when one-half the stroke has been performed, its efficacy will be raised by expansion to 1·69; if the admission of the steam be stopped at one-third of the stroke, the efficacy will be 2·10; at one-fourth 2·39; at one-fifth 2·61; at one-sixth 2·79; at one-seventh 2·95; at one-eighth 3·08. The expansion, however, cannot be carried beneficially so far as one-eighth, unless the pressure of the steam in the boiler be very considerable, on account of the inconvenient size of cylinder or speed of piston which would require to be adopted, the friction of the engine, and the resistance of vapour in the condenser, which all become relatively greater with a smaller urging force.

Q. Is this amount of benefit actually realised in practice?

A. Only in some cases. It appears to be indispensable to the realisation of any large amount of benefit by expansion, that the cylinder should be enclosed in a steam jacket, or should in some other way be effectually protected from refrigeration. In some engines not so protected, it has been found experimentally that less benefit was obtained from the fuel by working expansively than by working without expansion—the whole benefit due to expansion being more than counteracted by the increased refrigeration due to the larger surface of the cylinder required to develop the power. In locomotive engines, with outside cylinders, this condition of the advantageous use of expansion has been made very conspicuous, as has also been the case in screw steamers with four cylinders, and in which the refrigerating surface of the cylinders was consequently large.

Q. The steam is admitted to and from the cylinder by means of a slide or sluice valve?

A. Yes, and of the slide valve there are many varieties. The D valve, shown in fig. 34—and so called from its resemblance to a half cylinder or D in its cross section—is now little used, but the three-ported valve, shown in fig. 35, is still widely employed. This valve consists of a brass or iron box set over the two ports or openings into the cylinder, and a central port which conducts away the steam to the atmosphere or condenser; but the length of the box is so adjusted that it can only cover one of the cylinder ports and the central or eduction port at the same time. The effect, therefore, of moving the valve up and down, as is done by the eccentric, is to establish a connection alternately between each cylinder port and the central passage whereby the steam escapes; and while the steam is escaping

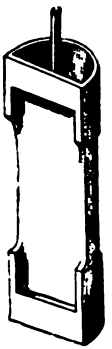
Fig. 34.
Long D Valve.

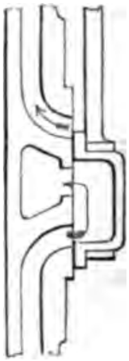
Fig. 35.
Three-ported Valve.

from beneath the piston, the position of the valve is such that a free communication exists between the space above the piston and the steam in the boiler. The piston is thus urged alternately up and down—the valve so changing its position before the piston arrives at the end of the stroke, that the pressure is by that time thrown on the reverse side of the piston, so as to urge it into motion in the opposite direction.

Q. Is the motion of the valve, then, the reverse of that of the piston?

A. No. The valve does not move down when the piston moves down, nor does it move down when the piston moves up; but it moves from its mid position to the extremity of its throw and back again to its mid position while the piston makes an upward or downward movement, so that the motion is, as it were, at right angles to the motion of the piston; or it is the same motion that the piston of another engine, the crank of which is set at right angles with that of the first engine, would acquire.

Q. Then in a steam vessel the valve of one engine may be worked from the piston of the other?

A. Yes, it may; or it may be worked from its own connecting rod; and, in the case of locomotive and marine engines, this is sometimes done.

LAP AND LEAD.

Q. What is meant by the lead of the valve?

A. The amount of opening which the valve presents for the admission of the steam, when the piston is just beginning its stroke. It is found expedient that the valve should have opened a little to admit steam on the reverse side of the piston before the stroke terminates; and the amount of this opening, which is given by turning the eccentric more or less round upon the shaft is what is termed the lead.

Q. And what is meant by the lap of the valve?

A. It is an elongation of the valve face to a certain extent over the port, whereby the port is closed sooner than would otherwise be the case. This extension is chiefly effected at that part of the valve where the steam is admitted, or upon the *steam side* of the valve, as the technical phrase is; and the intent of the extension is to close the steam passage before the end of the stroke, whereby the engine is made to operate to a certain extent expansively. In some cases, however, there is also a certain amount of lap given to the escape or eduction side, to prevent the eduction from being performed too soon when the lead is great; but in all cases there is far less lap on the eduction than on the steam side, very often there is none, and sometimes less than none, so that the valve is incapable of covering both the ports at once.

Q. What is the usual proportional length of stroke of the valve?

A. A common stroke of the valve in rotative engines is twice the breadth or depth of the port, and the length of the valve face will then be just the breadth of the port when there is lap on neither the steam nor eduction side. Whatever lap is given, therefore, makes the valve face just so much longer. In some engines, however, the stroke of the valve is a good deal more than twice the breadth of the port; and it is to the stroke of the valve that the amount of lap should properly be referred.

Q. Can you tell what amount of lap will accomplish any given amount of expansion?

A. Yes, when the stroke of the valve is known. From the length of the stroke of the piston subtract that part of the stroke which is intended to be accomplished before the steam is cut off; divide the remainder by the length of the stroke of the piston, and extract the square root of the quotient, which multiply by half the stroke of the valve, and from the product take half the lead; the remainder will be the lap required.

Q. Can you state how we may discover at what point of the stroke the eduction passage will be closed?

A. To find how much before the end of the stroke the eduction passage will be closed:—to the lap on the steam side add the lead, and divide the sum by half the stroke of the valve; find the arc whose sine is equal to the quotient, and add 90° to it; divide the lap on the eduction side by half the stroke of the valve, and find the arc whose cosine is equal to the quotient; subtract this arc from the one last obtained, and find the cosine of the remainder; subtract this cosine from 2, and multiply the remainder by half the stroke of the piston; the product is the distance of the piston from the end of the stroke when the eduction passage is closed.

Q. Can you explain how we may determine the distance of the piston from the end of the stroke, before the steam urging it onward is allowed to escape?

A. To find how far the piston is from the end of its stroke when the steam that is propelling it by expansion is allowed to escape to the atmosphere or condenser :—to the lap on the steam side add the lead ; divide the sum by half the stroke of the valve, and find the arc whose sine is equal to the quotient ; find the arc whose sine is equal to the lap on the eduction side, divided by half the stroke of the valve ; add these two arcs together and subtract 90° ; find the cosine of the residue, subtract it from 1, and multiply the remainder by half the stroke of the piston ; the product is the distance of the piston from the end of its stroke when the steam that is propelling it is allowed to escape into the atmosphere or condenser. In using these rules, all the dimensions are to be taken in inches, and the answers will be found in inches also.

IMPORTANCE OF LEAD.

Q. Is it a benefit or a detriment to open the eduction passage before the end of the stroke ?

A. In engines working at a high rate of speed, such as locomotive engines, it is very important to open the exhaust passage for the escape of the steam before the end of the stroke, as an injurious amount of back pressure is thus prevented. In the earlier locomotives a great loss of effect was produced from inattention to this condition ; and when lap was applied to the valves to enable the steam to be worked expansively, it was found that a still greater benefit was collaterally obtained by the earlier escape of the steam from the eduction passages, and which was incidental to the application of lap to the valves. The average consumption of coke per mile was reduced by Mr. Woods from 40 lbs. per mile to 15 lbs. per mile, chiefly by giving a free outlet to the escaping steam.

WIRE-DRAWING.

Q. To what extent can expansion be carried beneficially by means of lap upon the valve ?

A. To about one-third or one-half of the stroke ; that is, the valve may be made with so much lap, that the steam will be cut off when two-thirds or one-half of the stroke has been performed, leaving the residue to be accomplished by the agency of the expanding steam ; but if a much further amount of expansion than this is wanted, it may be accomplished by wire-drawing the steam, or by so contracting the steam passage that the pressure within the cylinder must decline when the speed of the piston is accelerated, as it is near the middle of the stroke.

Q. Will you explain how this result ensues?

A. If the valve be so made as to shut off the steam by the time one-half of the stroke has been performed, and the steam be at the same time throttled in the steam pipe, the full pressure of the steam within the cylinder cannot be maintained except near the beginning of the stroke, where the piston travels slowly; for, as the speed of the piston increases, the pressure necessarily subsides, until the piston approaches the other end of the cylinder, where the pressure would rise again but that the operation of the lap on the valve by this time has had the effect of closing the communication between the cylinder and steam pipe, so as to prevent more steam from entering. By throttling the steam, therefore, in the manner here indicated, the amount of expansion due to the lap may be increased to any desired extent.

EXPANSION VALVES.

Q. Is this the usual way of cutting off the steam?

A. No; the usual manner of cutting off the steam is by means of a separate valve, termed an expansion valve; but such a device appears to be hardly necessary in ordinary engines, especially if fitted with the link motion, by which a very efficient expansive action of the steam is obtainable by shortening the throw of the valve, which virtually increases the lap. In the Cornish engines, where the steam is cut off in some cases at one-twelfth of the stroke, a separate valve for the admission of steam, other than that which permits its escape, is adopted; but in common rotative engines a separate expansion valve does not appear to be required.

Q. Will you explain the configuration of expansion apparatus of the usual construction?

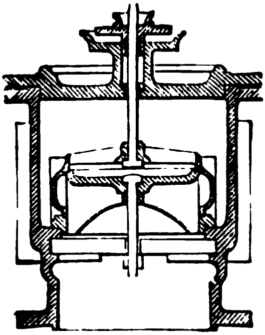

Fig. 36.
Cornish Equilibrium Valve.

A. The structure of expansion apparatus is very various; but all the kinds operate either on the principle of giving such a motion to the slide valve as will enable it to cut off the steam at the desired point, or on the principle of shutting off the steam by a separate valve in the steam pipe or valve casing. The first class of apparatus has not been found so manageable, and is not in extensive use, except in that form known as the link motion. A kind of expansion valve, often employed in marine engines of low speed, is the kind used in the Cornish engines, and known as the equilibrium valve. This valve is represented in fig. 36. It consists substantially of an annulus or bulging cylinder of brass, with a steam-tight face both at its upper and lower edges, at which point it fits accurately upon a stationary seat. This annulus may be raised or lowered without being resisted by the pressure of the steam, and in rotative engines it is usually worked by a cam or projection on the shaft.

LINK MOTION.

Q. What is Stephenson's arrangement for varying the admission given to the steam in his locomotives?

A. Stephenson connects the ends of the forward and backward eccentric rods by a link having a curved slot in which a pin upon the end of the valve rod works. By moving this link so as to bring the forward eccentric rod in the same line with the valve rod, the valve receives the motion due to that eccentric; whereas if the backward eccentric rod is brought in a line with the valve rod, the valve gets the motion proper for reversing, and if the link be so placed that the valve rod is midway between the two eccentric rods, the valve will remain nearly stationary. This arrangement, which is now employed extensively, is what is termed 'the link motion.' It is represented in the annexed figure (fig. 37), where *e* is the valve rod, which is attached by a pin to an open curved

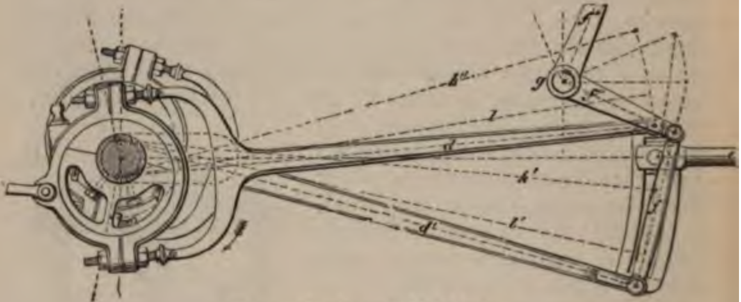

Fig. 37.—Stephenson's Link Motion.

link susceptible of being moved up and down by the bell-crank lever *f' f'*, supported on the centre *g*, and acting on the links *f*, while the valve rod *e* remains in the same horizontal plane; *d d'* are the eccentric rods, and the link is represented in its lowest position. The dotted lines *h' h''* show the position of the eccentric rods when the link is in its highest position, and *l l'* when in mid position.

Q. What other forms of apparatus are there for working steam expansively?

A. They are too numerous for description here, but a few of them may be enumerated. Fenton sought to accomplish the desired object by introducing a spiral feather on the crank axle, by moving the eccentric laterally against which the eccentric was partially turned round so as to cut off the steam at a different part of the stroke. Dodds sought to attain the same end by corresponding mechanical arrangements. Farcot, Edwards, and Lavagrian cut off the steam by the application of a supplementary valve at the back of the ordinary valve, which supplementary valve was moved by tappets fixed to the valve casing. Bodmer in 1841, and Meyer in 1842, employed two slides or blocks fitted over apertures in the ordinary slide valve, and which blocks were drawn together or set apart by a right and left handed screw passing through both.[1] Hawthorn, in 1843, employed as an expansion valve a species of frame lying on the ordinary cylinder face upon the outside of the valve, and working up against the steam side of the valve at each end so as to cut off the steam. In the same year Gonzenbach patented an arrangement which consisted of an additional slide valve and valve casing placed on the back of the ordinary slide valve casing, and through this supplementary valve the steam had first to pass. Modern marine engines are often fitted with gridiron expansion valves, formed with a movable perforated plate working on a fixed perforated plate in the steam pipe, and the travel is only the length of one of the perforations which, though small, will nevertheless from their number afford the required area for the passage of the steam.

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[1] In 1838 I patented an arrangement of expansion valve, consisting of two movable plates set upon the ordinary slide valve, and which might be drawn together or asunder by means of a right and left handed screw passing through both plates. The valve spindle was hollow, and a prolongation of the screw passed up through it, and was armed on the top with a small wheel, by means of which the plates might be adjusted while the engine was at work. In 1839 I fitted an expansion valve in a steam vessel, consisting of two plates, connected by a rod, and moved by tappets up against the steam edges of the valve. In another steam vessel I fitted the same species of valve, but the motion was not derived from tappets, but from a moving part of the engine, though at the moderate speed at which these engines worked I found tappets to operate well and make little noise.—J. B.

Q. Are expansion valves usual in modern locomotives?

A. No; and their use would be attended with some obvious inconveniences, one of which is that the expansion valves would have to be thrown out of action before the engines could be reversed, and the facility of handling would thus be impaired. If the steam were cut off much sooner than about ⅓rd of the stroke, then one engine would cease to get steam before the other began to get any, and the engines could neither be started nor reversed with facility, unless the expansive apparatus were previously detached. Upon the whole, it appears to be the best course to employ as much lap as can be introduced without impairing the tractability of the engine, and then to accomplish any further measure of expansion that may be desired by throttling the steam.

Q. Will the amount of expansive action be increased by diminishing the stroke of the valve?

A. It will, and this can easily be effected by altering the notch in which the starting lever of the link motion is held. To diminish the stroke of the valve is tantamount to increasing its lap, and this increases the amount of expansive action by shutting off the steam at an earlier part of the stroke. Throttling or wire-drawing the steam has much the same operation as with a contracted inlet, the steam can only keep up its pressure on the piston at the beginning of the stroke when the piston travels slowly, and as its speed accelerates towards mid-stroke the pressure falls.

CHAPTER I.

HISTORICAL ACCOUNT OF THE STEAM ENGINE.

EARLY PROJECTS FOR RAISING WATER BY STEAM.

Q. Who was the inventor of the steam engine, or what has been its history?

A. The steam engine had no individual inventor any more than the ship, or the loom, or the railway, but it has gradually grown up from small beginnings by the contributions of different persons—of whom by far the most important was James Watt—during the last century. Since his time very little real improvement has taken place in the steam engine, except in the introduction of better materials and workmanship, higher pressure and higher speed.

Q. Was any form of the steam engine known to the ancients?

A. The ancients had very vague ideas as to the nature of steam. They believed in the existence of four elements—fire, air, earth, and water, and thought that water was turned into air by heat. It is consequently often difficult to understand in the description of ancient pneumatic contrivances whether air or steam was the agent employed, and we have, indeed, generally to form our conclusion on this head from the nature of the arrangement. It appears clear, however, from the accounts of ancient inventions which have descended to us, that both steam and air expanded by heat were used as motive powers, and some of the combinations for this purpose were of considerable elegance. But they were all on a petty scale, more of the nature of toys than of useful apparatus, and were not employed for any purpose of public utility. One of these contrivances was the Ælopile, a hollow metal ball suspended by a wire or spindle, and with a lamp or charcoal fire placed beneath, so as to cause water introduced into the ball to boil. The steam was made to issue through a small pipe on each side of the ball, and these tubes were bent longitudinally at their extremities in opposite directions. The issuing steam caused the ball to rotate rapidly. There were also contrivances for forcing water up a pipe by the pressure of steam or air.

Q. What is the first known example of the application of steam to accomplish practical work of public importance?

A. The first known application of steam to perform useful work was made by the Marquis of Worcester, who set up an engine at Vauxhall for raising water. This engine was inspected by Cosmo de Medici in 1653, who states that it was accounted more useful to the public than another machine near Somerset House, which last was worked by horses.

Q. Were the ideas of the Marquis of Worcester carried out to any considerable extent in practice?

A. Yes, by Captain Thomas Savery, whose engine is shown in fig. 38. A A are the furnaces which contain the boilers; B 1, B 2, the two fireplaces; C the funnel, or chimney, which is common to both furnaces. In these two furnaces are placed two vessels of copper, which he called boilers, the one large, as L, the other small, as D; D the small boiler contained in the furnace which is heated by the fire at B 2; E the pipe and cock to admit cold water into the small boiler to fill it; F the screw that covers and confines the cock E to the top of the small boiler; G a small gauge cock at the top of a pipe, going within eight inches of the bottom of the small boiler; H a larger pipe, which goes the same depth into the small boiler; I a clack or valve at the top of the pipe H (opening upwards); K a pipe going from the box above the said clack or valve in the great boiler, and passing about an inch into it; L L the great boiler contained in the other furnace, which is heated by the fire at B 1; M the screw with the regulator, which is moved by the handle Z, and opens or shuts the apertures at which the steam passes out of the great boiler into the steam pipes O O; N a small gauge cock at the top of a pipe which goes half-way down into the great boiler; O 1, O 2, steam pipes, one end of each screwed to the regulator, the other ends to the receivers P P, to convey the steam rom the great boiler into those receivers; P 1, P 2, copper vessels called receivers, which are to receive the water which is to be raised; Q screw joints, by which the branches of the water-pipes are connected with the lower parts of the receivers; R 1, 2, 3, and 4, valves or clacks of brass in the water-pipes, two above the branches Q, and two below them; they allow the water to pass upwards through the pipes, but prevent its descent. There are screw plugs

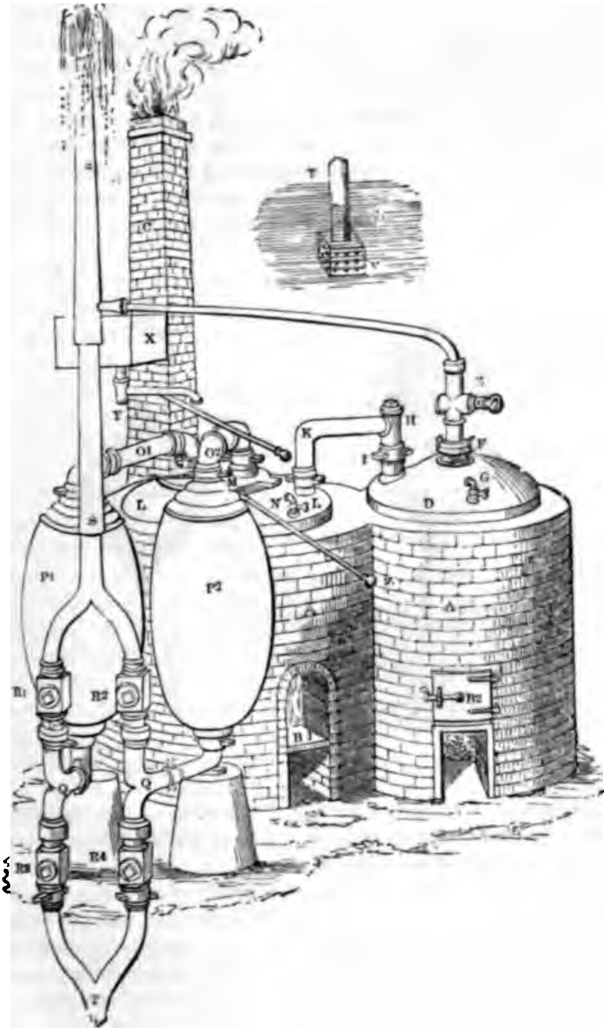


Fig. 38.—Savery's Fire Engine.

to take out on occasion, to get at the valves R. S is the forcing pipe which conveys the water upwards to its place of delivery, when it is forced out from the receivers by the impellent steam; T the sucking pipe, which conveys the water up from the bottom of the pit, to fill the receivers by suction; V a box, with holes perforated in it, to enclose the lower end of the sucking-pipe, to keep away dirt and obstructions; X a cistern with a buoy-cock coming from the force-pipe, so that it shall always be kept filled with cold water; Y a cock and pipe coming from the bottom of the said cistern, with a spout to let the cold water run down on the outside of either of the receivers P P; Z the handle of the regulator, to move it by, either open or shut, so as to let the steam out of the great boiler into either of the receivers.

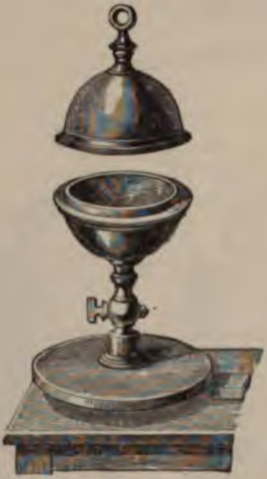


Fig. 39.

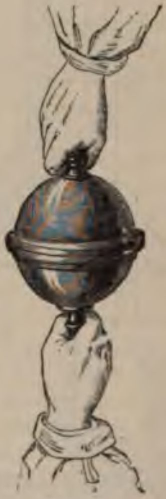


Fig. 40.

In 1643 Torricelli discovered the pressure of the atmosphere; and about 1650 Otto Guericke, of Magdeburg, without knowing what Torricelli had done, excited much popular astonishment by creating a vacuum within two brass hemispheres, such as are shown in figs. 39 and 40, when it was found that they could not be pulled asunder, although several horses of the Emperor, Charles V., were yoked to the opposite ends. The vacuum was produced by means of a small pump, by which the air was pumped out, and the experiment was modified in many ways to show the great pressure the atmosphere exerted. One form of apparatus employed was a cylinder, A, with an airtight piston moving within it, and by withdrawing the air from beneath the piston while the atmosphere pressed on its upper surface, the piston descended, drawing down the rope which passes over the pulleys B and C and lifting the weights deposited in the scale D (fig. 41).

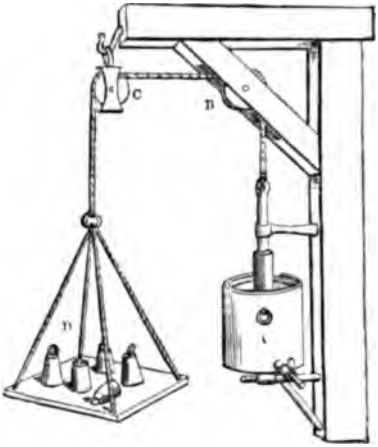


Fig. 41.—Vacuum Cylinder and Piston.

Q. Was not this more of the nature of a philosophical experiment than of a useful invention?

A. No doubt; but it gave the idea of employing a piston and cylinder with a vacuum beneath the piston as an expedient for raising heavy weights, and it only remained to find an easy way of producing the vacuum to turn a philosophical toy into a useful engine. In Savery's engine the vacuum was produced by the condensation of steam; but, in that engine, steam of a very high pressure had to be used, to overcome the gravity of the column of water in deep mines, and in those days of mechanical inexperience it was difficult to construct boilers strong enough to be at once safe and effective. About 1710 it was perceived by Thomas Newcomen, of Dartmouth, that, by using Otto Guericke's cylinder and piston, and by producing a vacuum by the condensation of steam, he could raise water from any desired depth, not by a very high pressure of steam, but by a large area of piston. He therefore applied a cylinder and piston at one end of a beam like that of a pair of scales, to work a pump at the other end, and the general outline of this arrangement is retained to the present day in pumping engines.

Q. How was the condensation of the steam effected in Newcomen's original engine?

A. By applying a water casing to the outside of the cylinder, which cooled the cylinder, and gradually condensed the steam within it. But having found, when working the engine on this plan, that from some cause it began after a time to work much faster than at first, they proceeded to investigate the cause, and found that a hole had been accidentally made in the cylinder, which allowed a jet of water to enter within it; and, acting on this hint, they thereupon fitted the cylinder with an internal jet of water. At first the valves were worked by hand. But a lad, who had been set to work an engine, found that by connecting the handles of the valves to the beam of the engine by strings the engine would work them more regularly than he could do, and that he would be thus dispensed from the necessity of such continuous attention. All the known improvements up to that time were combined in Smeaton's Chase-Water engine, erected in 1775, a representation of which is given in fig. 42. The cylinder of the Chase-Water engine was 72 inches in diameter; length of stroke 9 feet; number of strokes per minute $9 = 81$ feet of effective motion, and load upon the piston $7\frac{2}{3}$ lbs. This gives a power of about $76\frac{1}{2}$ horses, for $72^2 \times \cdot 7854 \times 81 \times 7\frac{2}{3} \div 33{,}000 = 76\frac{1}{2}$ HP. The configuration of these engines will be seen at once by a reference to fig. 42, where A B is the cylinder, C the piston made of iron and covered on the bottom with elm planking, secured with screw-bolts to the piston. Between this planking and the iron of the piston, tarred flannel is interposed to retard the transmission of heat, and thereby render the condensation within the cylinder less serious. D is the great lever, 27 feet 4 inches long, consisting of twenty pieces of fir, the four nearest the middle being 12 inches square, and the other sixteen being 6 inches by 12 inches. These pieces of timber are prevented from rubbing upon one another by means of oak keys, driven into mortices prepared for their reception, and are bolted together by 32 long iron bolts, 1 inch in diameter, passing through the whole depth of the lever. The axis of the lever, where it passes through the wood, is 30 inches wide by 5 inches thick. The bearings are $8\frac{1}{2}$ inches in diameter, resting in brass bushes, let into blocks of wood built into the lever wall. Breadth between bearings $3\frac{1}{2}$ feet; breadth of beam 2 feet; depth of beam at centre 74 inches; depth at extremities 60 inches. E is the lever wall; F F the beams which support the cylinder, or rather which keep it down, and which are retained in their places by the walls of the house; G is the boiler, H the furnace, I the steam pipe, J the injection pipe, terminating in a wooden jet-piece jammed between the steam pipe and the side of the cylinder, the use of wood in this situation being to diminish the condensation by a non-conducting substance. K is the cistern for holding the injection water, and

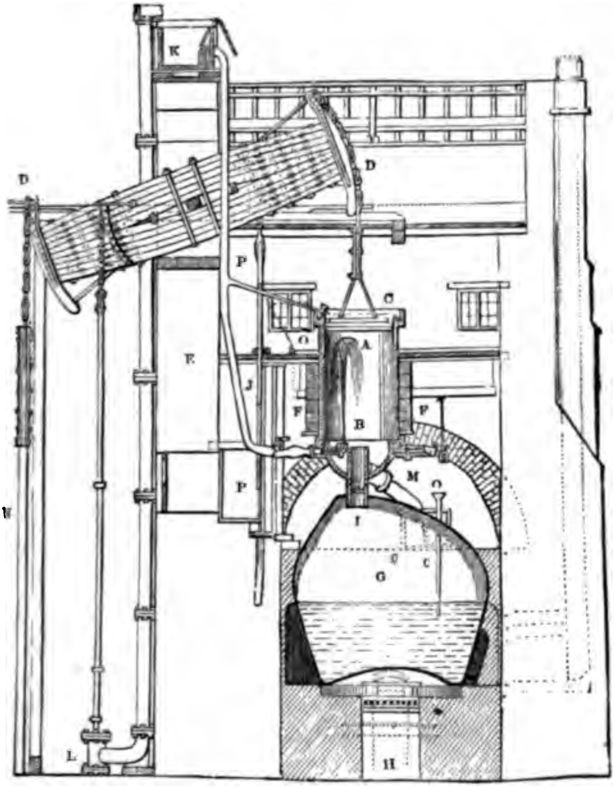


Fig. 42.—Chase-Water Engine, 1775.

which is placed in an elevated situation to cause the more perfect dispersion of the injection water by the force with which it enters the cylinder. L is a pump for raising the injection water into the cistern. M is the eduction pipe, terminating in the hot well, and fitted with a valve at its inferior extremity, to prevent the regurgitation of the water; N pump rod of the pump of the mine; O a band or strap extending to the cataract, shown in more detail in fig. 44; P P the plug rod, by which the valve gearing is wrought by means of projecting plugs or tappets. The steam pipe is 12 inches in diameter, the eduction pipe 8 inches; and the two short necks for the injection cock and snifting valve 6 inches diameter. These are all cast in the same piece with the hemispherical bottom. The snifting valve, for the expulsion of the air and water by the steam at each stroke, consists of a short plug of boxwood driven tight into its seat, fitted with a circular flap valve applied to the end of the plug. Over this a conical pipe is fixed with a cock at its extremity, so as to regulate the amount of the snift at pleasure. The upright feed pipe, Q, is designed to answer the double purpose of a lower gauge cock and a safety pipe.

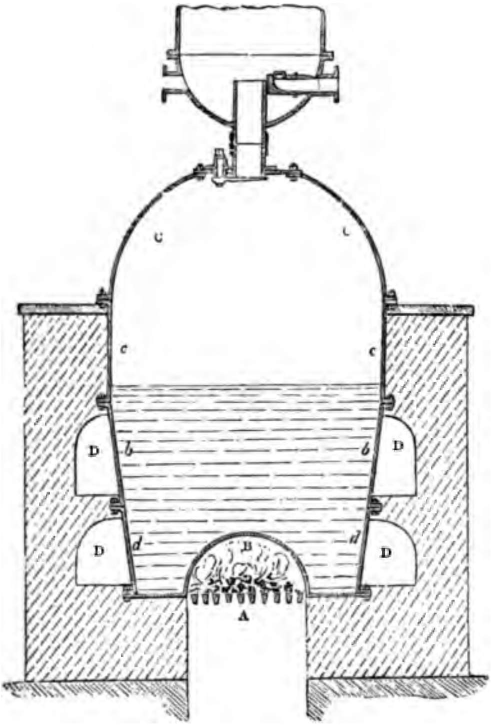


Fig. 43.—Smeaton's Haystack Boiler.

Q. What kind of boilers did Smeaton use?

A. Some of them were formed of wrought iron plates riveted together, and others of them were made of cast iron plates joined together by flanges. An example of a cast iron boiler of this kind is given in fig. 43, where A is the ashpit, B the furnace, C C the steam space, D D the flues, *c c* the tier of plates set in brickwork, and *b b*, *d d* the tiers exposed to the heat of the flues.

Q. How was the speed of these engines regulated?

A. The movement of the engine, when the quantity of work to be done was irregular, was commonly regulated by a contrivance called the cataract, or, as it was termed by the miners, the Jack-in-the-box. This apparatus consists merely of a small cock *z* (fig. 44), through which a drip of water is suffered to pass into the vessel, Y, situated within the box, Z, and so poised upon a centre, in connection with the lever, U, that U will preponderate when Y is empty, but not when it is full. When Y becomes full, it will tilt over in the direction indicated by the dotted lines, raising the catch 18 by the chain 22, and by this act will empty itself of the water, and resume its original position. The water flows away out of the box, Z, which is lined with lead, after having performed its function in raising the catch; and the catch, when raised, releases a weight, which opens the injection valve, and the engine makes a stroke. The number of reciprocations, therefore, of the cataract determines the number of strokes made by the engine, so that the speed of the engine is thus regulated by the degree of opening given to the cock *z*, and which is determined by the quantity of water to be drawn. The cataract is not a contrivance of Smeaton's, but was used in the Cornish engines before his time. A much better variety than that here figured is now employed, which will be described in its proper place.

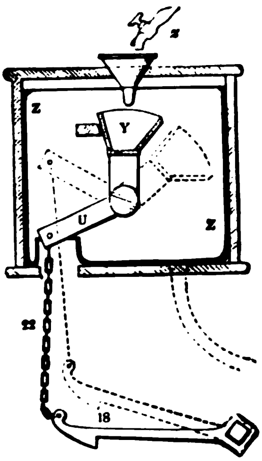


Fig. 44.—Cataract.

WATT'S IMPROVEMENTS IN THE STEAM ENGINE.

Q. What was the nature of Watt's great improvement in the steam engine?

A. His first great improvement was condensing the steam in a separate vessel, which he called the condenser, instead of in the cylinder, as in Newcomen's engine; and by this simple expedient

d a great saving in fuel, as the cylinder could thus be
ays hot and the condenser always cold, instead of the
being alternately heated and cooled at each stroke. This
ement was patented by him in 1769. He afterwards made
gine double-acting, introduced the principle of working the
n expansively, contrived means for enabling the engine to
art equable circular motion, and in fact converted the steam
gine of Newcomen into what the steam-engine substantially is at
he present day.

Q. Did not Hornblower devise means of using the same steam twice over—first in a high-pressure cylinder of small size, and next in a low-pressure or condensing cylinder of large size; and is economy derived from the use of this principle?

A. Watt showed when Hornblower's plan was promulgated in 1781 that there is no greater economy obtained by the use of two cylinders, one working high pressure, and the other low pressure, than by using the steam expansively in one cylinder, and all subsequent experience has justified the accuracy of this conclusion.

Q. Will you describe the structure of Hornblower's engine?

A. The form of this engine will be understood at once by a
glance at the accompanying sketch (fig. 45), where A is the larger
cylinder; B the smaller one; C and D their respective piston
rods; G a square pipe for supplying the small cylinder with steam
from the boiler; K is the eduction pipe leading to the condenser,
L, which stands on the box M, and to which are fixed the pumps
O and N, for extracting the air and water; P is a cold water cis-
tern in which the condenser stands; U is the hot well to which
the water is conveyed from the air pumps by the trough T; and
into the hot well the feed pump V dips to obtain water for th
boiler; W is the plug rod; and X the pump rod of the mine.
S a valve is situated to admit cold water into the conden
and P is a pipe leading from the condenser, closed on the top
a valve which serves as a blow-through valve. *a b c d* are
two of which are the reciprocal of the other two, and whic
blish the requisite communications between the boiler
cylinders. When *d* and *a* open, and *b* and *c* are shut, th
from the boiler enters through *d* above the piston of
from beneath the piston of B enters above the
At the same time the valve situated in t
the cylinder, is open, and the en

stroke. Again, when *b* and *c* are open, and *a* and *d* shut, a communication is established between each side of the respective

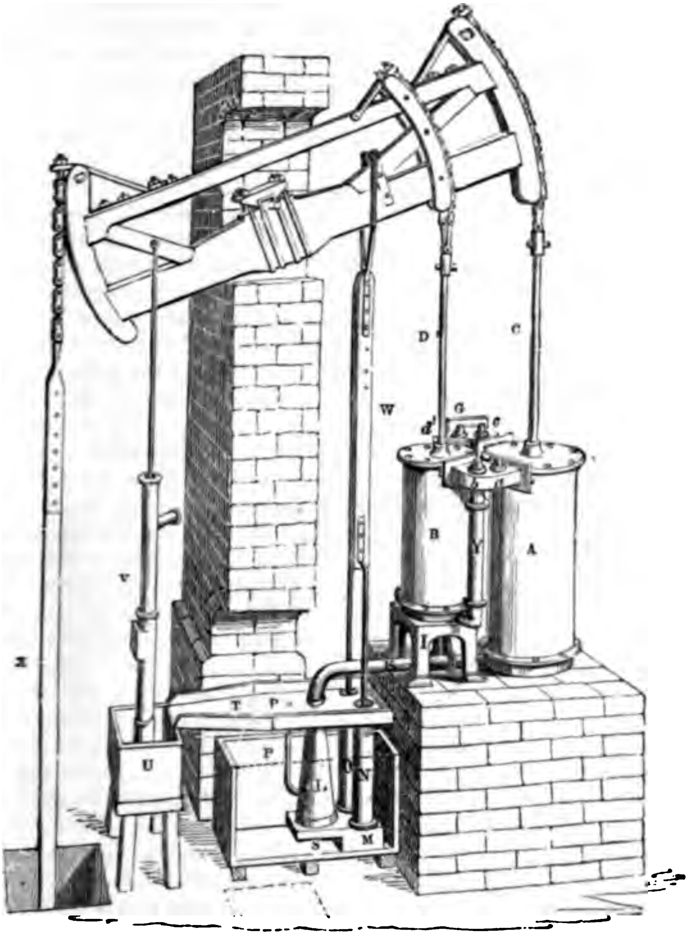


Fig. 45.—Hornblower's Double-Cylinder Engine, 1781.

pistons; and, as an equilibrium of pressure is thus produced, the pistons rise by virtue of the preponderance of the pump end of the

There is a great deal of manifest plagiarism in this engine; ndenser and air pump, the cylinder covers with their stuffing , and indeed everything good about the engine, is evidently owed from Mr. Watt, with the single exception of the two nders ; and by them nothing was accomplished that had not n already attained by Mr. Watt quite as effectually with a single linder only.

Q. Will you state the precise purpose and describe the struc- ure of Watt's early engines?

A. In the earlier portion of his career at Soho, Watt restricted his efforts in the application of his engine to the single function of pumping water, and it was only after he had perfected its operation in this species of work, that he turned his attention to the production of rotatory motion from the reciprocating engine. The form that his single-acting engine had attained at the time that he began to apply his engine to the production of rotatory motion is represented in fig. 46, where A is the cylinder, B the piston, C the piston rod, E the cylinder steam casing, F the steam pipe, G the steam valve, by which the admission of steam to the cylinder is restrained or prevented, H the boiler, I the prolongation of the steam pipe to the equilibrium valve K, L the eduction valve, M the condenser, J the eduction pipe, N the injection cock, O the foot valve, P the air pump, Q the air pump bucket, S the delivery valve communicating with the hot well, T the suction pipe of the feed pump, U the feed pump, V the cold water pump for lifting the injection water into the cold water cistern, Y the valve handles, which are moved by tappets on the plug tree, Z, suspended from the beam; *a* is the body of the beam, *b* the main centre; *c*, *c* truss rods, proceeding from the central upright, *d*, to each end of the beam, to obviate deflection; *e*, *e* arch heads, to which the chains of the piston rod and pump rod accommodate themselves, *g* a small arch head for giving motion to the air-pump bucket, on the rod o which the plug tree is affixed; *h*, *j* counterbalance weights; suction valve of the pump; *o*, *o* flues encircling the boiler; P f nace; *r* damper in the flue leading to the chimney. The man in which this engine operates is easily comprehended. In thi in the atmospheric engine, the piston necessarily stands at th of the cylinder when the engine is at rest, in consequence ponderance given to the pump end of the beam, and th ting the engine is to expel the air with which th and the several pipes and passag become filled. This is accomplished by relieving the handles of the steam, equilibrium, and eduction valves of their several catches, when the valves immediately fall open by the gravitation of weights with which they are connected, and the steam finds an access to the whole internal part of the engine. At first it is rapidly condensed by coming into contact with the cold metal; but as the iron becomes hot the steam flows onward, expelling the air before it, and finally issues at the snifting or blow valve, situated on the lower part of either the air pump or condenser. The valves must now be shut, and a vacuum will quickly be produced within the engine by the condensation of the steam. The blowing through may be repeated two or three times in order to expel the air effectually, and the symptom of its thorough expulsion is the sharp crackling noise made by the steam at the snifting valve, which is

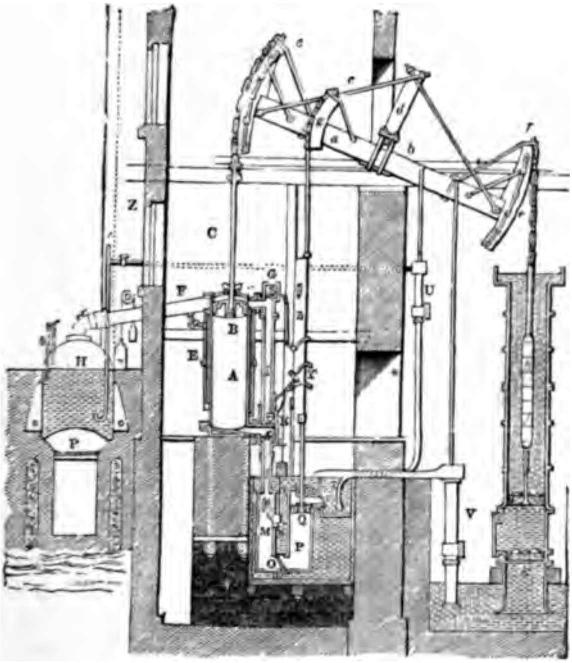


Fig. 46.—Watt's Single-Acting Engine, 1788.

caused by the rapid condensation of the steam when unmixed with air by the water suffered to lie in the snifting valve chest to keep the valve tight. When the engine has been thoroughly cleared of air by blowing through, the steam and eduction valves are opened at the same time, the equilibrium valve remaining shut, and the injection cock is also opened. The steam then pressing upon the superior surface of the piston, while there is a vacuum underneath it, forces the piston down. The plug tree in its descent closes the steam and eduction valves, and opens the equilibrium valve, which establishes an equality of pressure above and beneath the piston, and the piston then rises in consequence of the pump end of the beam being the heaviest. The plug tree in its ascent closes the equilibrium valve, and opens the steam and eduction valves, and the action is thus perpetuated. The water admitted by the injection cock is discharged by the pump P into the hot well S, from whence a sufficiency of water is drawn by the small pump U, to replenish the boiler. No improvement in the principle of the single-acting or pumping engine has taken place since its parts were arranged by Watt in the manner here delineated. The great lever indeed is now made of iron instead of wood, parallel motions, also invented by Watt, are employed instead of arch heads and chains, and some improvements have been made in the details of the valve gearing and other minutiæ. But these modifications, though they make the instrument more elegant and convenient, do not make it more effectual; and an engine made after Watt's primitive type would, with an equally effectual boiler, and an equal measure of clothing and expansion, do about the same amount of duty as the best of the modern constructions.

Q. What was the purport of Watt's second patent?

A. Watt's second patent for improvements on the steam engine was for the production of rotatory motion. It was taken out in 1781, and is stated to be 'for certain new methods of applying the vibratory or reciprocatory motion of steam or fire engines to produce a continued rotative or circular motion round an axis or centre, and thereby to give motion to the wheels of mills or other machines.' In this patent, among various other ways of producing circular from reciprocating motion, occurs the contrivance known as sun and planet wheels.

Q. What is the nature of sun and planet wheels?

A. A toothed wheel is fixed on the axis of the fly wheel in the position in which the crank is placed in modern engines. Another similar wheel is fixed on the end of the connecting rod, and the two wheels are connected by a link which, when the engine is set to work, compels the wheel on the end of the connecting rod to circulate round the other wheel, putting it into rotation with twice the speed that a crank would do.

Q. Is such a contrivance as eligible for the production of circular motion as a crank would be?

A. No; but at the time the application was made Watt was precluded from using a crank as he had originally intended, from another person having forestalled him in taking out a patent for it, and so he had to invent this alternative contrivance, which was applied to many engines with success.

Q. Will you give an example of such application.

A. I will select for this purpose one of the engines of the Albion Mills, where it was first applied, and of which a representation is given in fig. 47. The steam pipe conveys steam from the boiler to the cross pipe, or upper steam-nozzle G, and by the perpendicular steam pipe to the lower steam-nozzle. In the nozzle G is a valve, which, when open, admits steam into the cylinder above the piston through the horizontal square pipe at its top; and in the lower steam nozzle there is another valve, which, when open, admits steam into the cylinder below the piston. In the upper exhaustion nozzle is a valve, which, when open, admits steam to pass from the cylinder above the piston into the exhaustion pipe J, which conveys it to the condensing vessel M, where it meets the jet of the injection from the cock N, and is reduced to water; and, in the lower exhaustion nozzle, there is also a valve, which, when open, admits steam to pass out of the cylinder below the piston, by the eduction pipe, into the condenser M.

The piston being at the top of its stroke, the valves G and L are to be opened, and the fly-wheel *m* turned by hand about one-eighth of a revolution, or more, in the direction in which it is intended to move; the steam which is then in the cylinder will pass by L into the condenser, when, meeting the jet of water from the injection-cock, it will be converted into water; and the cylinder thus becoming exhausted, the steam, entering the cylinder by the valve G, will press upon the piston and cause it to descend, while, by its action upon the working beam through the piston rod, &c., it pulls down the cylinder end of the beam, and raises up the other end and the connecting rod *h*, which causes the planet wheel, *i*, to tend to revolve round the sun wheel *j*; but the former of these wheels, being fixed upon the connecting rod so that it cannot turn upon its own axis, and its teeth being engaged in those of the sun wheel, the latter, and the fly-wheel upon whose axle or shaft it is fixed, are made to revolve in the desired direction, and give motion to the mill-work.

As the piston descends, the plug tree, Z, also descends, and a clamp or slider, *q*, fixed upon the side of the plug tree, presses upon the handle, I, of the upper Y-shaft or axis, and thereby shuts the valves G and L; and the same operation, by disengaging a detent, permits a weight suspended to the arm of the lower Y-shaft to turn the shaft upon its axis, and thereby to open the other valves. The moment previous to the opening these valves the piston had reached the lowest part of its stroke, and the cylinder *above* the piston was filled with steam; but as soon as H is opened, that steam rushes by the eduction pipe, J, into the condenser, and *the cylinder above* the piston is exhausted. The steam from the

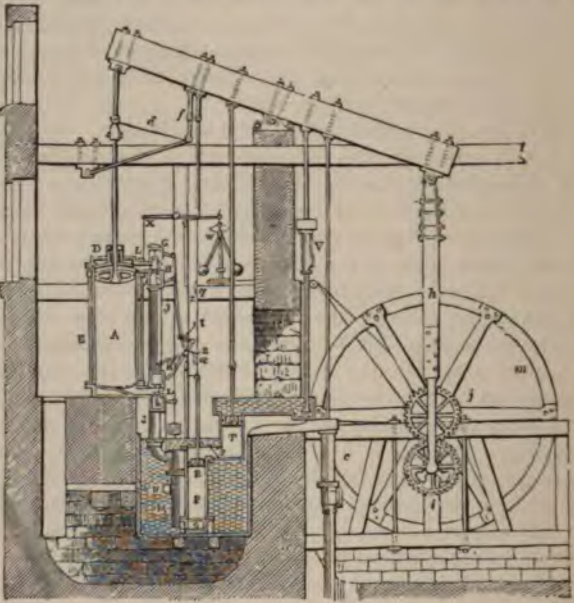


Fig. 47.—Watt's Double-Acting Rotative Engine, 1788.

boiler entering by I and K acts upon the *lower* side of the piston, and forces it to return to the top of the cylinder. When the piston is very near the upper termination of its stroke, another slider, *a*, raises the handle, and in so doing disengages the catch which permits the upper Y-shaft to revolve upon its own axis, and open the valves G and L, and the downward stroke commences, as has been related. When the piston descends, the buckets, R T, of the air pump P, and hot-water pump T, also descend. *d*, *f* are the rods and links of the parallel motion, W the governor communicating with the throttle valve L, by means of the lever X. The second pump, T, is not used in modern engines, and the sun and planet wheels have given place to the crank; but this engine is capable of as good a performance as the best engines now made. It is worthy of remark that at the Albion Mills two engines were employed with what answered for the cranks set at right angles. This is the first example of an arrangement which has now become universal in steam vessels, locomotives, and elsewhere, requiring equability of motion or facility of stopping and starting.

Q. What was the common form of boiler employed by Watt in these early engines?

A. The waggon boiler, of which a perspective representation is given in fig. 48. It is a long rectangular vessel, with a rounded top, like that of a carrier's waggon, from its resemblance to which it derives its name. A fire is set beneath it, and flues constructed of brickwork encircle it, so as to keep the flame and smoke in contact with the boiler for a sufficient time to absorb the heat. This species of boiler has not an internal furnace, but is set in brickwork, in which the furnace is formed. The general arrangement and configuration will be at once understood by a reference to the annexed figure (fig. 48), which is a perspective view of a waggon boiler. The grate and a part of the flues are rendered visible in the figure by the removal of a portion of the surrounding masonry in which the boiler is set. The interior of the boiler A is also shown by cutting off one-half of the semicircular roof. The door by which the fuel is introduced to the grate is represented at B. A door is also represented at C, leading to the ash-pit; but in land boilers doors are not commonly applied in this situation. The fire-bars slope downwards from the front at an angle of about 25°, giving the fuel a tendency to move towards the back of the grate. The ash-pit E is constructed of sufficient magnitude to enable a sufficient supply of air to ascend through the grate bars G, and the flame passes over a low wall or bridge at F, and traverses the bottom of the boiler. The smoke rises up at the back of the boiler, and proceeds from H to I, through the flue shown in that *situation*—with its upper part removed—which encircles the boiler.

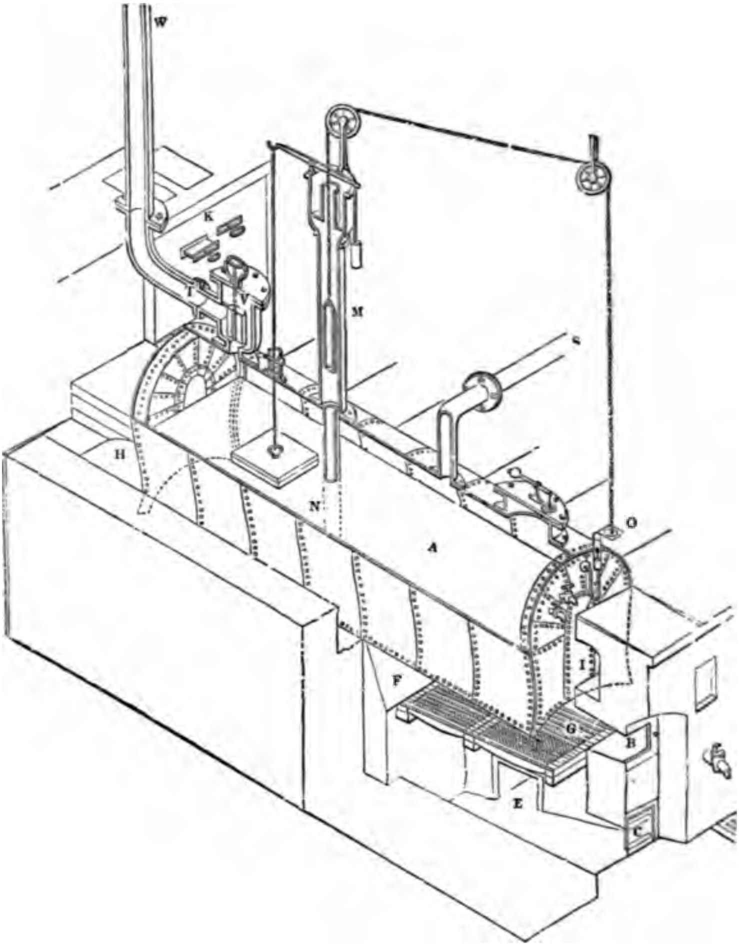


Fig. 48.—Waggon Boiler, with part of top removed.

It proceeds on in this flue to K, and then ascends the chimney. The performance of this course by the smoke is what is termed a wheel draught, as the smoke wheels once round the boiler.

Q. Is the performance of this course by the smoke universal in waggon boilers?

A. No; such boilers sometimes have what is termed a split draught. The smoke and flame, when they reach the end of the boiler, pass in this case through an iron flue or tube, reaching from end to end of the boiler; and on arriving at the position of K, the smoke splits or separates—one half passing through a flue on the one side of the boiler, and the other half passing through a flue on the other side of the boiler—both of these flues having their debouch in the chimney.

Q. There appear to be several pipes leading out of the boiler.

A. On the top of the boiler, near the front, is a short cylinder, with a lid secured by bolts. This is the man-hole door, the purpose of which is to enable a man to get into the inside of the boiler when necessary for inspection and repair. On the top of this door is a small valve opening downwards, called the atmospheric valve. The intention of this valve is to prevent a vacuum from being formed accidentally in the boiler, which might collapse it; for if the pressure in the boiler subsides to a point materially below the pressure of the atmosphere, the valve will open and allow air to get in. The bent pipe S, which rises up from the top of the boiler, immediately behind the position of the man-hole, is the steam pipe for conducting the steam to the engine; and the bent pipe T which ascends from the top of the boiler, at the back end, is the waste steam pipe for conducting away the steam, which escapes through the safety valve V. This valve is set in a chest, standing on the top of the boiler, at the foot of the waste steam pipe, and it is loaded with iron or leaden weights to a point answerable to the intended pressure of the steam.

Q. How is the proper level of the water in the boiler maintained?

A. By means of a balanced buoy or float, which in this boiler is square, and which may be seen at the surface of the water. This float is attached to a rod, which in its turn is attached to a lever, set on the top of the large upright pipe M. The upper part of the pipe M is widened out into a small cistern, through a short pipe in the middle of which a chain passes to the damper; but any water emptied into this small cistern cannot pass into M except through a small valve fixed to the lever to which the rod is attached, but which is not shown in this figure, to avoid complication. The water for replenishing the boiler is pumped into the small cistern; and it follows from these arrangements that when the buoy falls, the rod opens the small valve and allows the feed water to enter M, which communicates with the water in the boiler; whereas, when the buoy rises, the feed cannot enter M, and it has, therefore, to run to waste through an overflow pipe provided for the purpose.

Q. How is the strength of the fire regulated?

A. The draught through the furnaces of land boilers is usually regulated by a plate of metal, or a damper, as it is called, which slides like a sluice up and down in the flue, and this damper is closed more or less when the intensity of the fire has to be moderated. In waggon boilers this is generally accomplished by self-acting mechanism. In the pipe M, which is called a stand pipe, the water rises up to a height proportional to the pressure of the steam, and the surface of the water in this pipe will rise or fall with the fluctuations in the pressure of the steam. In this pipe a float is placed, which communicates by means of a chain with the damper at O. If the pressure of the steam rises, the float will be raised and the damper closed, whereas, if the pressure in the boiler falls, the reverse of this action will take place.

Q. Are all land boilers of the same construction as that which you have just described?

A. No; many land boilers are now made of a cylindrical form, with one or two internal flues in which the furnace is placed.

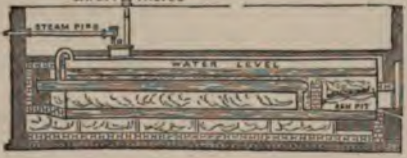


Fig. 49.
Cornish Boiler, Longitudinal Section.

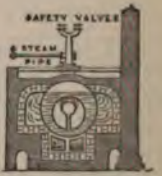


Fig. 50.—Cornish Boiler, Transverse Section.

A boiler of this kind is represented in figs. 49 and 50, and which is the species of boiler principally used in Cornwall. In this boiler a large internal cylinder or flue runs from end to end. In the fore part of this cylinder the furnace is placed, and behind the furnace a large tube filled with water extends to the end of the boiler. This internal tube is connected to the bottom part of the boiler by a copper pipe standing vertically immediately behind the furnace bridge, and to the top part of the boiler by a bent copper pipe which stands in a vertical position near the end of the boiler. The smoke, after passing through the central flue, circulates round the sides and beneath the bottom of the boiler before its final escape into the chimney. The boiler is carefully covered over to prevent the dispersion of the heat.

WATT'S ENGINE WITH CRANK.

Q. Will you describe the structure of Watt's rotative engine at a later date than the engines at the Albion Mills, when he had introduced his various improvements?

A. The structure and action of the double-acting land engine of the kind introduced by Mr. Watt, after he was enabled to use the crank, will be understood by a reference to the annexed figure (fig. 51), where an engine of this kind is shown in section. C is the cylinder in which a movable piston, P, is forced alternately up and down by the alternate admission, to each side, of the steam from the boiler. The piston, by means of the piston rod, gives motion to the beam H*f*, which by means of O, the connecting rod, moves the crank, G, and with it the fly wheel, F, from which the machinery to be driven derives its motion.

Q. Where does the steam enter from the boiler?

A. At the steam pipe, S. The throttle valve in that pipe is an elliptical plate of metal swivelling on a spindle passing through its edge from side to side, and by turning which more or less the opening through the pipe will be more or less closed. The extent to which this valve is opened or closed is determined by the governor, Q, the balls of which, as they collapse or expand, move up or down a collar on the governor spindle, which motion is communicated to the throttle valve by suitable rods and bell-cranks. The governor, it will be seen, consists substantially of two heavy balls attached to arms fixed upon an upright shaft, which is kept in revolution by means of a cord driven by a pulley on the fly wheel shaft. The velocity with which the balls of the governor revolve being proportional to that of the fly wheel, it will follow, that if by reason of too rapid a supply of steam, an undue speed be given to the fly wheel, and therefore to the balls, a divergence of the balls will take place to an extent corresponding to the excess of velocity, and this movement being communicated to the throttle valve it will be partly closed, the supply of steam to the engine will be diminished, and the velocity of its motion will be reduced If, on the other hand, the motion of the engine is slower than is requisite, owing to a deficient supply of steam through S, then the balls, not being sufficiently affected by centrifugal force, will fall towards the vertical spindle, and the throttle valve, T, will be more fully opened, whereby a more ample supply of steam will be admitted to the cylinder, and the speed of the engine will be increased to the requisite extent.

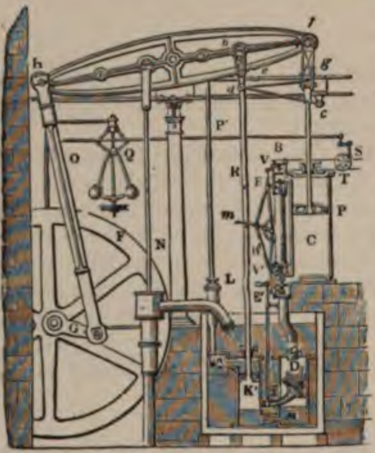


Fig. 51.—Double-acting Rotative Steam Engine with Crank.

Q. The piston must be made to fit the cylinder accurately so as to prevent the passage of steam?

A. The piston is accurately fitted to the cylinder, and made to move in it steam-tight by a packing of hemp driven tightly into a groove or recess round the edge of the piston, and which is squeezed down by an iron ring held by screws. The piston divides the cylinder into two compartments, between which there is no communication by which steam or any other elastic fluid can pass. A casing B B′, set beside the cylinder, contains the valves, by means of which the steam which impels the piston is admitted and withdrawn, as the piston commences its motion in each direction. The upper steam-box B is divided into three compartments by two valves. Above the upper steam-valve V is a compartment communicating with the steam-pipe S. Below the lower valve E is another compartment communicating with the pipe called the eduction pipe, which leads downwards from the cylinder to the condensers, in which vessel the steam is condensed by a jet of col water. By the valve V, a communication may be opened or close between the boiler and the top of the cylinder, so as to permit c prevent a supply of steam from the one to pass to the other. By the valve E a communication may be opened or closed between the top of the cylinder and the condenser, so that the steam in the top compartment of the cylinder may either be permitted to escape into the condenser, or may be confined to the cylinder. The continuation of the steam pipe S′ leads to the lower steam-box B′, which, like the upper, is divided into three compartments by two valves V′ and E, and the action of the lower valves is in all respects the same as that of the upper.

Q. Are all these valves connected together, so that they act simultaneously?

A. The four valves V E, V′ E′ are connected by rods to a single handle *m*, which handle is moved alternately up and down by means of pins or tappets, placed on the rod which works the air pump. When the handle *m* is pressed down, the levers in connection with it open the upper exhausting valve E and the lower steam valve V′, and close the upper steam valve V and the lower exhausting valve E′. On the other hand, when the handle *m* is pressed up it opens the upper steam valve V and the lower exhausting valve E′, and at the same time closes the upper exhausting valve E and the lower steam valve V′.

Q. Where is the condenser situated?

A. The condenser D is immerged in a cistern of cold water. At its side there is a tube I, for the admission of water to condense the steam, and which is governed by a cock, by opening which to any required extent, a jet of cold water may be made to play in the condenser. From the bottom of the condenser a short pipe leads to the air pump K′, and in this pipe there is the flap valve M, called the foot valve, opening towards the air pump. The air pump is a pump set in the same cistern of cold water that holds the condenser, and it is fitted with a piston or bucket worked by the rod R, attached to the great beam, and fitted with a valve opening upwards in the manner of a common sucking pump. The upper part of the air pump communicates with a small cistern K, called the hot well, through a valve opening outwards and called the delivery valve. A pump L, called the hot water pump, lifts hot water out of the hot well to feed the boiler, and another pump N lifts cold water from a well or other source of supply, to maintain the supply of water to the cold water cistern, in which the condenser and air pump are placed.

Q. Will you explain now the manner in which the engine acts?

A. The piston being supposed to be at the top of the cylinder, the handle *m* will be raised by the lower pin or tappet on the air pump rod, and the valves V and E′ will be opened, and at the same time the other pair of valves V′ and E will be closed. Steam will therefore be admitted above the piston, and the steam or air which had previously filled the cylinder below the piston will be drawn off to the condenser. It will there encounter the jet of cold water, which is kept constantly playing there by keeping the cock I sufficiently open. It will thus be immediately condensed or reduced to water, and the cylinder below the piston will have a vacuum in it. The steam therefore admitted from the steam pipe through the open valve V to the top of the cylinder, not being resisted by pressure below, will press the piston to the bottom of the cylinder. As it approaches that position, the handle *m* will be struck down by the upper pin or tappet on the air-pump rod, and the valves V and E′, previously open, will be closed, while the valves V′ and E, previously closed, will be opened. The steam which has just pressed down the piston, and which now fills the cylinder above the piston, will then flow off, through the open valve E, to the condenser, where it will be immediately condensed by the jet of cold water; and steam from the boiler, admitted through the open valve V′, will fill the cylinder below the piston, and press the piston upwards. When the piston has reached the top of the cylinder, the lower pin on the air-pump rod will have struck the handle upwards, and will thereby have closed the valves V′ and E, and opened the valves V and E′. The piston will then be in the same situation as in the commencement, and will again descend, and so will continue to be driven up and down by the steam.

Q. But what becomes of the cold water which is let into the condenser to condense the steam?

A. It is pumped out by the air pump in the shape of hot water, its temperature having been raised considerably by the admixture of the steam with it. When the air-pump piston ascends it leaves behind it a vacuum; and the foot valve M, being relieved from all pressure, the weight of the water in the condenser forces it open, and the warm water flows from the condenser into the lower part of the air pump, from which its return to the condenser is prevented by the intervening valve. When the air-pump piston descends, its pressure on the liquid under it will force open the valve in it, through which the hot water will ascend; and when the bucket descends to the bottom of the pump barrel, the warm water which was below it will all have passed above it, and cannot return. When the bucket next ascends, the water above it, not being able to return through the bucket valve, will be forced into the hot well through the delivery valve K. The hot water pump L pumps a small quantity of this hot water into the boiler, to compensate for the abstraction of the water that has passed off in the form of steam. The residue of the hot water runs to waste.

Q. By what expedient is the piston rod enabled to pass through the cylinder cover without leaking steam out of the cylinder or air into it?

A. The hole in the cylinder lid, through which the piston rod passes, is furnished with a recess called a stuffing box, into which a stuffing or packing of plaited hemp is forced, which, pressing on the one side against the interior of the stuffing box, and on the other side against the piston rod, which is smooth and polished, prevents any leakage in this situation. The packing of this stuffing box is forced down by a ring of metal tightened by screws. This ring, which accurately fits the piston rod, has a projecting flange, through which bolts pass for tightening the ring down upon the packing; and a similar expedient is employed in nearly every case in which packing is employed.

Q. In what way is the piston rod connected to the great beam?

A. The piston rod is connected to the great beam by means of two links, one at each side of the beam, shown at *f g*. These links are usually made of the same length as the crank, and their purpose is to enable the end of the great beam to move in the arc of a circle while the piston rod maintains the vertical position. The point of junction, therefore, of the links and the piston rod is of the form of a knuckle or bend at some parts of the stroke.

Q. But what compels the top of the piston rod to maintain the vertical position?

A. Some engines have guide rods set on each side of the piston rod, and eyes on the top of the piston rod engage these guide rods, and maintain the piston rod in a vertical position in every part of the stroke. More commonly, however, the desired end is attained by means of the contrivance called the parallel motion.

Q. What is the parallel motion?

A. The parallel motion is an arrangement of jointed rods, so connected together that the divergence from the vertical line at any point in the arc described by the beam is corrected by an equal and opposite divergence due to the arc performed by the jointed rods during the stroke; and as these opposite deviations mutually correct one another, the result is that the piston rod moves in a vertical direction.

Q. Will you explain the action more in detail?

A. The pin which passes through the end of the beam at *f* has a link *f g* hung on each side of the beam, and a short cross bar, called a cross head, extends from the bottom of one of these links to the bottom of the other, which cross head is perforated with a hole in the middle for the reception of the piston rod. There are similar links *b d* at the point of the main beam, where the air-pump rod is attached. There are two rods *d g* connecting the links *b d* with the links *f g*, and these rods, as they always continue parallel to the main beam throughout the stroke, are called *parallel bars*. Attached to the ends of these two rods at *d* are two other rods *c d*, of which the ends at *c* are attached to stationary pins, while the ends at *d* follow the motion of the lower ends of the links *b d*. These rods are called the *radius bars*. Now it is obvious that the arc described by the point *d*, with *c* as a centre, is opposite to the arc described by the point *g*, with *d* as a centre. The rod *d g* is, therefore, drawn back horizontally by the arc described at *d* to an extent equal to the versed sine of the arc described at *g*, or, in other words, the line described by the point *g* becomes a straight line instead of a curve.

Q. Does the air-pump rod move vertically as well as the piston rod?

A. It does. The air-pump rod is suspended from a cross head, passing from the centre of one of the links *b d* to the centre of the other link, on the opposite side of the beam. Now, as the distance from the central axis of the great beam to the point *b* is equal to the length of the rod *c d*, it will follow that the upper end of the link will follow one arc, and the lower end an equal and opposite arc. A point in the centre of the link, therefore, where these opposite motions meet, will follow no arc at all, but will move up and down vertically in a straight line.

Q. The use of the crank is to obtain a circular motion from a reciprocating motion?

A. That is the object of it, and it accomplishes its object in a very perfect manner, as it gradually arrests the velocity of the piston towards the end of the stroke, and thus obviates what would otherwise be an injurious shock upon the machine. When the crank approaches the lowest part of its throw, and at the same time the piston is approaching the top of the cylinder, the motion of the crank becomes nearly horizontal, or, in other words, the piston is only advanced, through a very short distance, for any given distance measured on the circle described by the crank pin. Since, then, the velocity of rotation of the crank is nearly uniform, it will follow that the piston will move very slowly as it approaches the end of the stroke; and the piston is brought to a state of rest by this gradually retarded motion, both at the top and the bottom of the stroke.

Q. What causes the crank to revolve at a uniform velocity?

A. The momentum of the machinery moved by the piston, but more especially of the fly wheel, which by its operation redresses the unequal pressures communicated by the crank, and compels the crank shaft to revolve at a nearly uniform velocity. Everyone knows that a heavy wheel, if put into rapid rotation, cannot be immediately stopped. At the beginning and end of the stroke when the crank is vertical, no force of torsion can be exerted on the crank shaft by the crank, but this force is at its maximum when the crank is horizontal. From the vertical point, where this force is nothing, to the horizontal point, where it is at its maximum, the force of torsion exerted on the crank shaft is constantly varying; and the fly wheel by its momentum redresses these irregularities, and carries the crank through that 'dead point,' as it is termed, where the piston cannot impart any rotative force.

Q. Are the configuration and structure of the rotative steam engine, as it left the hand of Watt, materially different from those of modern engines?

A. There is not much difference. In modern rotative land engines, the valves for admitting the steam to the cylinder or condenser, instead of being clack or pot-lid valves moved by tappets on the air-pump rod, are usually sluice or sliding valves, moved by an eccentric wheel on the crank shaft. Sometimes the beam is discarded altogether, and malleable iron is more largely used in the construction of engines instead of the cast iron which formerly so largely prevailed. But upon the whole the steam engine of the present day is substantially the engine of Watt; and he who perfectly understands the operation of Watt's engine, will have no difficulty in understanding the operation of any of the numerous varieties of engines since introduced.

STEAM NAVIGATION AND THE MARINE ENGINE.

Q. In what way did the application of the steam engine to the propulsion of vessels originate?

A. Such an application had often been proposed, but towards the end of last century Mr. Miller, of Dalswinton, proposed to work composite vessels consisting of several parallel hulls by means of paddle wheels placed between them, and he had such vessels constructed and tested. The wheels were rotated by capstans, and on the occasion of one of the trials James Taylor, a tutor in Mr. Miller's family, took a spell at the capstans and found it very heavy work. He accordingly suggested the application of a steam engine to turn them, which he said William Symington, a friend of his, could make, and Mr. Miller sanctioned the application, which was made, and successfully tried on Dalswinton lake in Scotland. In 1802 another and better vessel was constructed by Symington for the Forth and Clyde canal, which was quite successful as a steam vessel, but was laid aside because it was said to injure the banks of the canal. This steam vessel was inspected by Fulton, an American, who in 1807 commissioned Boulton and Watt to make a steam engine for him for the propulsion of a steamer in America. In 1812 Henry Bell, who had also frequently inspected Symington's boat, built the 'Comet,' propelled by a 4 horse-power engine and four paddle wheels. Steam vessels of an improved type thereafter followed, and soon became very numerous.

Q. Are all steam vessels propelled by paddle wheels?

A. No; the majority are now propelled by the screw, an instrument formed with oblique arms, or vanes, like the blades of a windmill, and which is rapidly rotated beneath the water at the stern. The screw was introduced by Sir F. P. Smith and John Ericsson about 1838. But it was a number of years before it came into extended use. It is now almost universal for the propulsion of ocean vessels. But in the case of river vessels the paddle wheels are still preferred.

Q. Then are there different classes of marine engines, each appropriate to the particular propeller employed?

A. Marine engines are of two kinds—paddle engines and screw engines. Of each class there are many distinct varieties.

PADDLE ENGINES.

Q. What are the principal varieties of the paddle engine?

A. There is the side lever engine and the oscillating engine, besides numerous other forms of engine which are less known or employed, such as the trunk, double cylinder, annular, Gorgon, steeple, and many others. The side lever engine, however, and the oscillating engine, are the only kinds of paddle engines which have been received with wide or general favour, or have come into extended use.

Q. Will you explain the main distinctive features of the side lever engine?

A. In all paddle vessels, whatever be their subordinate characteristics, a great shaft of wrought iron, turned round by the engine, has to be carried from side to side of the vessel, on which shaft are fixed the paddle wheels. The paddle wheels may either be formed with fixed float-boards for engaging the water, like the boards of a common undershot water-wheel, or they may be formed with *feathering* float-boards, as they are termed, which is float-boards movable on a centre, and so governed by appropriate mechanism that they enter and leave the water in a nearly vertical position. The fixed floats are attached by bolts to the arms of two or more rings of malleable iron, which are fixed by appropriate centres on the paddle shaft, and the feathering floats swing on horizontal spindles. It is usual in steam vessels to employ two engines, the cranks of which are set at right angles with one another. When the paddle wheels are turned by the engines, the float boards engaging the water cause a forward thrust to be imparted to the shaft, which propels forward the vessel on the same principle that a boat is propelled by the action of oars.

Q. These remarks apply to all paddle vessels?

A. They do. With respect to the side lever engine, it may be described to be such a modification of the land beam engine, already described, as will enable it to be got below the deck of a vessel. With this view, instead of a single beam being placed overhead, two beams are used, one of which is set on each side of the engine as low down as possible. The cross head which engages the piston rod is made somewhat longer than the diameter of the cylinder, and two great links or rods proceed one from each end of the cross head to one end of the side levers or beams. A similar cross bar at the other end of the beams serves to connect them to one another and to the connecting rod, which, proceeding from thence upwards, engages the crank, and thereby turns round the paddle wheels.

Q. Will you further illustrate this general description by an example?

A. I will take as an example the engines constructed by Messrs. Boulton and Watt for the steamers 'Red Rover' and 'City of Canterbury,' and which were in successful and constant use for a great number of years. Fig. 52 is a longitudinal section of both engine and boiler; X X represent the beams or keelsons to which the engines are attached, and on which the boilers rest. The engines are tied down by strong bolts passing through the bottom of the vessel, but the boiler keeps its position by its weight alone; S is the steam pipe leading from the steam chest of the boiler to the slide or sluice valve *c*, by which the steam is admitted alternately to the top and bottom of the cylinder. B is the condenser and E the air pump, which is worked off the side levers by means of side rods and a cross head. A strong gudgeon, called the *main centre*, passes through the condenser at K, the projecting ends of which serve to support the side levers or beams. F is the hot well, out of which the feed pump draws water to replenish the boiler, which is forced through the pipe I I. L is the piston rod, which, by means of the cross head and side rods, is connected to the side levers or beams, one of which is shown in dotted lines at H H, as being at the back of the engine, the other being supposed to be removed to enable the engine to be shown in section. M is the connecting rod, to which motion is imparted by the beams, through the medium of the cross tail extending between the beams, and which by means of the crank turns the paddle shaft O. The framing upon which the paddle shaft rests is denoted by Q R, and the rods of the parallel motion by *a a*. The eccentric which works the slide valve is placed upon the paddle shaft. It consists of a disc of metal encircled by a hoop, to which a rod is attached, and the disc is perforated with a hole for the shaft, not in the centre but near one edge. When, therefore, the shaft revolves, carrying the eccentric with it, the rod attached to the encircling hoop receives a reciprocating motion, just as it would do if attached to a crank in the shaft. The section of the boiler flues is represented by W U, the safety valve by *y*; and *h h* are cocks, by which the water in the boiler is blown out into the sea by the pressure of the steam, when the boilers require to be emptied, and also through which a portion of the water in the boiler is blown out from time to time, while the engine is at work, in order to prevent the sea water from reaching an injurious amount of concentration.

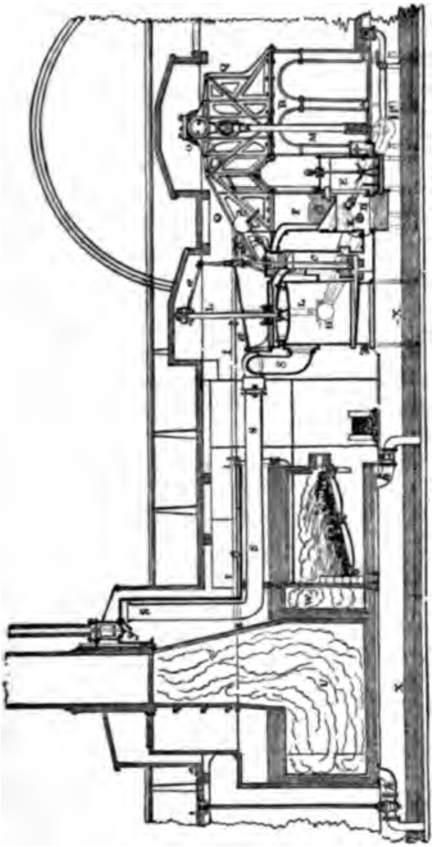


Fig. 52.—Side-lever Marine Engines and Flue Boilers. By Messrs. Boulton and Watt. Longitudinal section through vessel.

Q. Will you describe the mode of starting the engine?

A. I may first mention that when the engine is at rest, the connection between the eccentric and the slide valve is broken, by lifting the end of the eccectric rod out of a notch, which engages a pin on the valve shaft; and the valve is at such times free to be moved by hand by a bar of iron, applied to a proper part of the valve gear for that purpose. This being so, the engineer, when he wishes to start the engine, first opens a small valve called the *blow through valve*, which permits steam from the boiler to enter the engine both above and below the piston, and also to fill the condenser and air pump. This steam expels the air from the interior of the engine, and also any water which may have accumulated there; and when this has been done, the blow through valve is shut, and a vacuum very soon forms within the engine, by the condensation of the steam. If now the slide valve be moved by hand, the steam from the boiler will be admitted on one side of the piston, while there is a vacuum on the other side, and the piston will, therefore, be moved in the desired direction. When the piston reaches the end of the stroke, the valve has to be moved in the reverse direction, when the piston will return, and after being moved thus by hand, once or twice, the connection of the valve with the eccentric is to be restored by allowing the notch on the end of the eccentric rod to engage the pin on the valve lever, when the valve will be thereafter moved by the engine in the proper manner. It will, of course, be necessary, when the engine begins to move, to open the injection cock a little, to enable water to enter for the condensation of the steam. In the most recent marine engines, a somewhat different mechanism from this is used for giving motion to the valves, but that mechanism will be afterwards described.

Q. Are all marine engines condensing engines?

A. Nearly all of them are so; but special vessels have at times been constructed with high-pressure engines. In general, however, marine engines are condensing engines, and modern engines are for the most part constructed with surface condensers, so as to feed the boilers with fresh water.

Q. Will you now describe the chief features of the oscillating paddle marine engine?

A. In the oscillating paddle marine engine the arrangement of the paddle shaft and paddle wheels is the same as in the case already described; but the whole of the side levers, side rods, cross head, cross tail, and connecting rod are discarded. The cylinder is set immediately under the crank; the top of the piston rod is connected immediately to the crank pin; and, to enable the piston rod to accommodate itself to the movement of the crank, the cylinder is so constructed as to be susceptible of vibrating or oscillating upon two external axes or trunnions. These trunnions are generally placed about half-way up on the sides of the cylinder; and through one of them steam is received from the boiler, while through the other the steam escapes to the condenser. The air pump is usually worked by means of a crank in the shaft, which crank moves the air-pump bucket up and down as the shaft revolves.

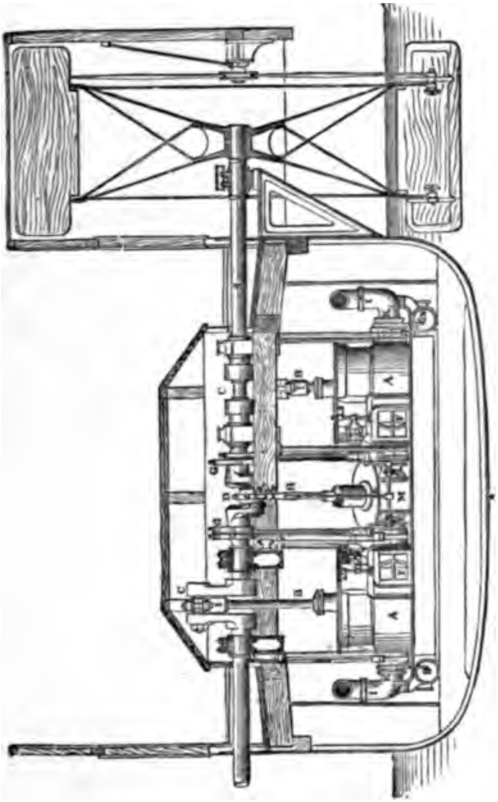


Fig. 53. Oscillating Marine Engines. By Messrs. Rennie.
Transverse section through vessel.

Q. Will you give an example of a paddle oscillating engine?

A. I will take as an example the oscillating paddle engines constructed by Messrs. Rennie for the steamer 'Peterhoff'; and this vessel was also fitted with feathering wheels. Fig. 53 is a transverse section of this vessel, showing the engines and wheels; and fig. 54 is a side view of the engines, showing also one of the wheels. There were two cylinders in this vessel, and one air pump, which lay in an inclined position, and is worked by a crank in the shaft, which stretches between the cylinders, and which is called the *intermediate shaft.* A A (fig. 53) are the two cylinders, B B the two piston rods, and C C the two cranks. D is the crank in the intermediate shaft, which works the air pump E; F F are the slide valves, by which the admission of the steam to the cylinders is regulated. G G are double eccentrics fixed on the shaft, whereby the movement of the slide valves is regulated. The purpose of the double eccentrics is to enable the arrangement of valve gear to be employed known as the *link motion.* H is a handle whereby the engine may be instantly stopped, started, or reversed, without the necessity of detaching the eccentric rod from the valve motion, as is necessary where the link motion is not employed. I I are the steam pipes leading to the steam trunnions K K, on which, and on the eduction trunnions connected with the pipe M, the cylinders oscillate. In fig. 54, N N are pumps, the pistons of which are attached to the trunnions, and are worked by the oscillation of the cylinders; O, in the same figure, is the waste water pipe, through which is discharged overboard the whole of the water lifted out of the condenser by the air pump, except that small portion employed for feeding the boiler.

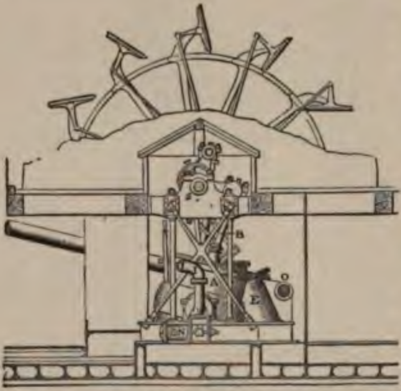


Fig. 54.—Oscillating Marine Engines. By Messrs. Rennie. Longitudinal section through vessel.

Q. By what species of mechanism are the positions of the paddle floats of this vessel governed?

A. The floats are supported by spurs projecting from the rim of the wheel, and they are moved upon the points of the spurs, to which they are attached by pins, by means of short levers proceeding from the backs of the floats, and connected to rods which proceed towards the centre of the wheel. The centre, however, to which these rods proceed is not concentric with the wheel, and the rods, therefore, are moved in and out as the wheel revolves, and impart a corresponding motion to the floats. In some feathering wheels the proper motion is given to the rods by means of an eccentric on the ship's side.

SCREW ENGINES.

Q. What are the principal varieties of screw engines?

A. The engines employed for the propulsion of screw vessels are divided into two great classes—geared engines and direct-acting engines; and each of these classes again has many varieties. In screw vessels, the shaft on which the screw is set requires to revolve at a much greater velocity than is required in the case of the paddle shaft of a paddle vessel; and in geared engines this necessary velocity of rotation is obtained by the intervention of toothed wheels—the engines themselves moving with the usual velocity of paddle engines; whereas, in direct-acting engines, the required velocity of rotation is obtained by accelerating the speed of the engines, which are connected immediately to the screw shaft.

Q. Will you describe some of the principal varieties of geared engines?

A. Geared engines are now obsolete, but for many years they held their ground with remarkable tenacity. A good many of the geared engines for screw vessels were made in the same manner as land engines, with a beam overhead, which, by means of a connecting rod extending downwards, gave motion to the crank shaft, on which was set the cog wheels, which gave motion to pinions on the screw shaft—the teeth of the wheels being generally of wood, and the teeth of the pinions of iron. There were usually several wheels on the crank shaft and several pinions on the screw shaft; but the teeth of each did not run in the same line, but were set a little in advance of one another, so as to divide the length of the tooth into as many parts as there were independent wheels or pinions. By this arrangement the wheels worked more smoothly than they would otherwise do.

Q. What other forms were there of geared screw engines?

A. In some cases the cylinders were placed on their sides in the manner of the cylinders of a locomotive engine. In some cases

vertical trunk engines were employed, and in other cases vertic
oscillating engines.

Q. Will you give an example of a geared vertical oscillatin
engine?

A. I will give as an example of this species of engine the geare

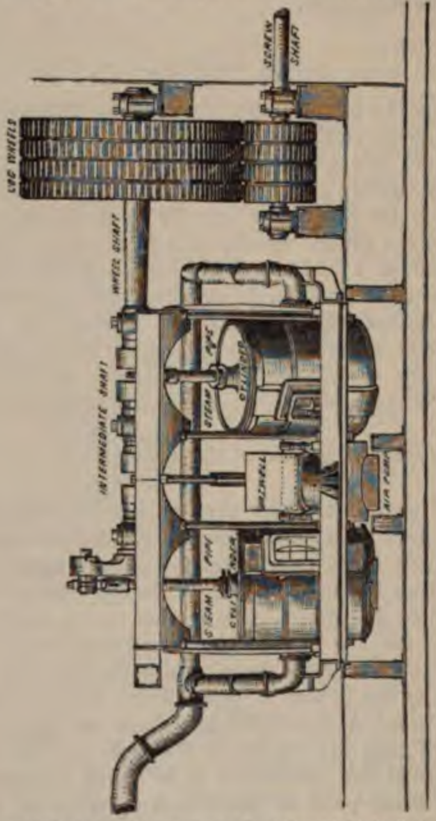


Fig. 55.—Geared Marine Screw Engines of the 'Great Britain' Steamer.
By Messrs. John Penn and Son.

oscillating engines of the steamship 'Great Britain,' constr
Messrs. John Penn and Son, and which are represented i
These engines in all their main features, except in the use of
are identical in construction with the oscillating paddle e
the same makers. The names of the principal parts of t

being written upon them, any detailed description of the engine is not required. The engines of the 'Great Britain' were made off the same patterns as the paddle engines constructed by Messrs. John Penn and Son for H.M.S. 'Sphinx.' The diameter of each cylinder is 82½ inches, the length of travel or stroke of the piston is 6 feet, and the nominal power is 500 horses. The 'Great Britain' is of 3,500 tons burden, and her displacement at 16 feet draught of water is 2,970 tons. The diameter of the screw is 15½ feet, length of screw in the line of the shaft 3 feet 2 inches, and the pitch of the screw 19 feet. The vessel, which is still plying (in 1884), has in all respects been eminently successful.

Q. What do you mean by the pitch of the screw?

A. A screw propeller may be supposed to be a short piece cut off a screw of large diameter like a spiral stair, and the pitch of a spiral stair is the vertical height from any given step to the step immediately overhead.

Q. What is the usual number of arms?

A. Sometimes a screw has two arms, but more frequently it has three or more. The 'Great Britain' had three arms. The multiple of the gearing in the 'Great Britain' is 3 to 1, and there are 17½ square feet of heating surface in the boiler for each nominal horse-power. The crank shaft, being put in motion by the engine, carries round with it the great cog wheel, or aggregation of cog wheels, affixed to its extremity; and these wheels, acting on suitable pinions on the screw shaft, cause the screw to make three revolutions for every revolution made by the engine.

Q. What are the principal varieties of direct-acting screw engines?

A. In some cases four engines have been employed instead of two, and the cylinders have been laid on their sides on each side of the screw shaft. This multiplication of engines, however, introduces needless complication, and is now but little used. In other cases two inverted cylinders are set above the screw shaft on appropriate framing; and connecting rods, attached to the ends of the piston rods, turn round cranks in the screw shaft. This is the system now in greatest favour.

Q. What is the kind of direct-acting screw engine introduced by Messrs. Penn, with the object of keeping the engine below the water line, for war vessels?

A. It is a horizontal trunk engine, and is represented in section in fig. 56. In this engine a round pipe, called a trunk, penetrates the piston to which it is fixed, being, in fact, cast in one piece with it; and the trunk also penetrates the top and bottom of the cylinder through which it moves, and is made tight therein by means of stuffing-boxes. The connecting rod is attached at one end to a pin fixed in the middle of the trunk, while the other end engages the crank in the usual manner. The air pump is set within the condenser, and is wrought by a rod which is fixed to the piston and derives its motion therefrom. The air pump is of that species which is called double-acting. The piston or bucket is formed without valves in it. but an inlet and outlet valve is fixed

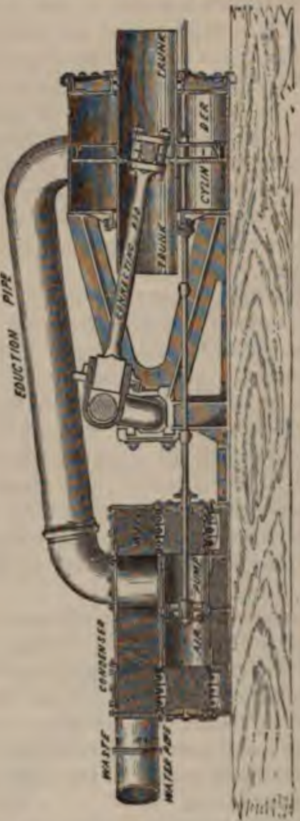


Fig. 56.—Direct-acting Marine Screw Engines. By Messrs. John Penn and Son. Longitudinal section.

to each end of the pump, through one of which the water is drawn into the pump barrel, and through the other of which it is expelled into the hot well.

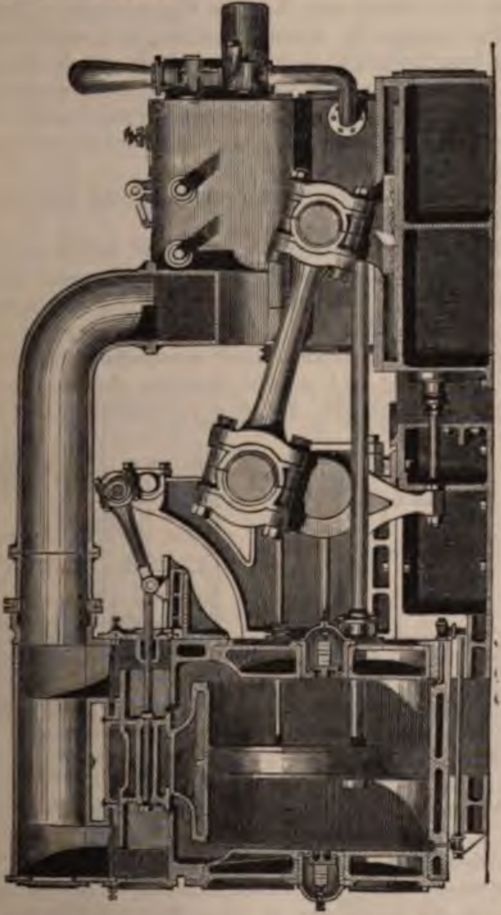


Fig. 57.—Longitudinal section of Engines of the 'Friedland.'

Q. Can horizontal screw engines be kept below the water without the use of a trunk?

A. Yes; and many such have been constructed. The first engines below the water-line were designed by Ericsson for the American war steamer 'Princeton,' and they were without a trunk, as were also the engines of the 'Pomone' and 'Amphion,' designed by him for the French and English Governments. These last engines were formed with return connecting rods, and this type of engine was long favourably regarded. An example of this species of engine is given in fig. 57, which represents the engines of the 'Friedland,' an armoured vessel belonging to the French Government. These engines were shown in operation at the International Exhibition at Paris in 1867.

Q. What kind of boilers were commonly used with these and other marine engines?

A. The boiler of the 'Comet' was a land boiler set in brickwork. But boilers with internal furnaces and internal flues soon came to be adopted. Boulton and Watt's marine boiler, shown in fig. 52, is a boiler of this kind. But the structure of an ordinary marine-flue boiler will be more clearly apprehended by a reference to figs. 58 to 62. Fig. 58 is a front elevation, showing the mouths of the furnaces and ash-pits. Fig. 59 is a horizontal section through A B, fig. 61; and fig. 60 is a horizontal section through C D, fig. 61. Fig. 61 is a vertical section through G H, fig. 60. In fig. 61 the general configuration of the boiler is very clearly represented; and the smoke, after winding first through the lower tier of flues, and next through the upper tier of flues, finally debouches at the chimney.

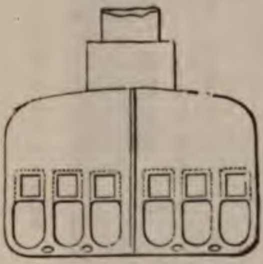


Fig. 58.—Marine Flue Boiler. Elevation.

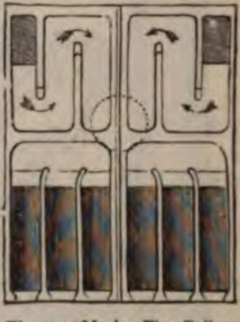


Fig. 59.—Marine Flue Boiler. Horizontal section through furnaces.

Q. Is this arrangement different from that obtaining in tubular boilers?

A. In tubular boilers, the smoke after leaving the furnace just passes once through a number of small tubes and then enters the chimney. These tubes are sometimes of brass, and they are usually about 3 inches in diameter and 6 or 7 feet long. Figs. 62 and 63 represent a marine tubular boiler; fig. 62 being a vertical longitudinal section, and fig. 63 being half a front elevation and half a transverse section. There is a projecting part on the top of the boiler called the 'steam chest,' of which the purpose is to retain

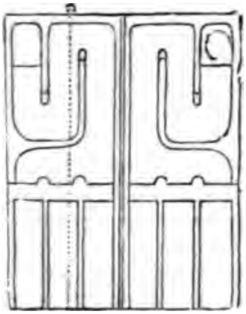


Fig. 60.—Marine Flue Boiler.
Horizontal section through flues.

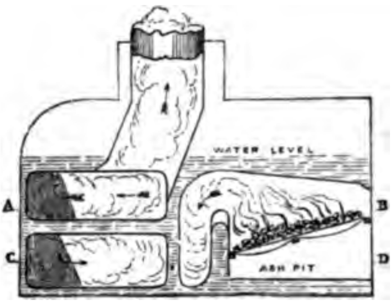


Fig. 61. - Marine Flue Boiler.
Longitudinal section.

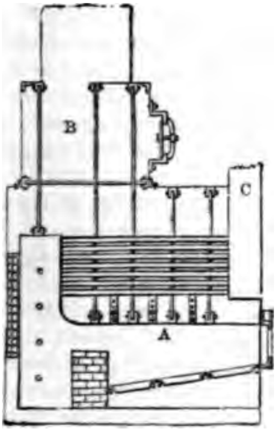


Fig. 62.—Tubular Marine Boiler.
Longitudinal section.

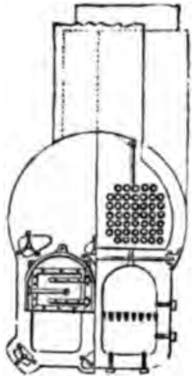


Fig. 63.—Tubular Marine Boiler.
Half elevation, half section.

for the use of the cylinder a certain supply of steam in a quiescent state, in order that it may have time to clear itself of foam or spray. A steam chest is a usual part of all marine boilers, working at a low pressure of steam. In fig. 62 A is the furnace, B the steam chest, and C the smoke-box which opens into the chimney. The front of the smoke-box is usually closed by doors, which may be opened when necessary to sweep the soot out of the tubes.

Q. Wherein do modern marine boilers differ from those which you have here described?

A. Modern marine boilers invariably work with a considerable pressure of steam, never under 60 lbs. per square inch, and often a good deal more. They are therefore always made circular, and always strong, being formed of thick plates with double-riveted seams. They are also invariably fed with fresh water, obtained by condensing the steam by thin metal pipes through which water is forced, and which pipes condense the steam in the same way that is done by the worm of a still.

RAILWAYS AND THE LOCOMOTIVE ENGINE.

Q. In what way did the railway system take its origin?

A. The first railways were made with wooden rails, and were introduced around Newcastle to facilitate the conveyance of coals from the pits to the port for shipment. These wooden railways were afterwards covered with sheet iron to make them wear better, and finally the wooden rails were discarded, and iron bars substituted, supported by cross sleepers.

Q. And what is the history of the application of the steam engine to the propulsion of carriages on railways?

A. The use of a portable engine to propel carriages on common roads was one of Watt's projects; and, in 1784, Murdoch, who was Watt's agent in Cornwall, constructed a small locomotive engine, and afterwards made one with which he ran about the roads in Cornwall. In 1802 Trevithick, a Cornish engineer, constructed an engine for drawing carriages or waggons on railways, and various persons constructed such engines after this time. Among them was George Stephenson, whose original locomotive engine was very imperfect. But, in 1824, Mr. James Kennedy, afterwards of the firm of Bury, Curtis and Kennedy, became George Stephenson's foreman, and he so improved the structure of the engine that, when the engines for the Stockton and Darlington

Railway were made in the following year, they achieved so decided a success that the Liverpool and Manchester Railway was immediately projected, and George Stephenson was made the engineer of it. The directors of this railway invited engineers to compete for a prize given for the best engine; and this trial, which came off in 1830, resulted in the prize being awarded to Robert Stephenson, the son of George Stephenson. The engine with which this success was achieved was called the 'Rocket,' and both it and the engine of the 'Comet,' the first British steamer which continued to ply for hire, may be seen at the patent museum in South Kensington. A correct representation of the engine of the 'Rocket' in its original state is given in fig. 64. As now shown at South Kensington it is not in its original form, but embodies changes subsequently introduced.

Q. With whom did the introduction of small tubes for the transmission of the smoke originate?

A. With M. Seguin, a French engineer. Mr. Henry Booth, the original secretary of the Liverpool and Manchester Railway, recommended the system to the attention of Robert Stephenson, who adopted it.

Q. Was the boiler of the 'Rocket,' as originally constructed, fitted with a blast pipe in the chimney?

A. No; and as a consequence the draught through the furnace was very defective, and the generation of steam insufficient. One of the other competing engines, however, was furnished with a blast pipe, which had been applied under the direction of Goldsworthy Gurney, who had assisted Trevithick in his early trials, and who, about 1830, had been endeavouring to establish steam coaches upon common roads. Trevithick had accidentally found that, by projecting the educted steam up the chimney, the activity of the fire was much increased; and by the use of this expedient, the locomotive fitted with it acquired a manifest advantage over its competitors. This was made clear by the preliminary trials of the several competing engines before the public trial was made; and the night before the public trial Stephenson had the 'Rocket' altered so as to project the educted steam up the chimney, as was done in Gurney's arrangement. This at once remedied the defective draught, and made the boiler an eminent success. The steam jet was afterwards applied by Gurney for the ventilation of mines and public buildings, and for such purposes is still largely employed.

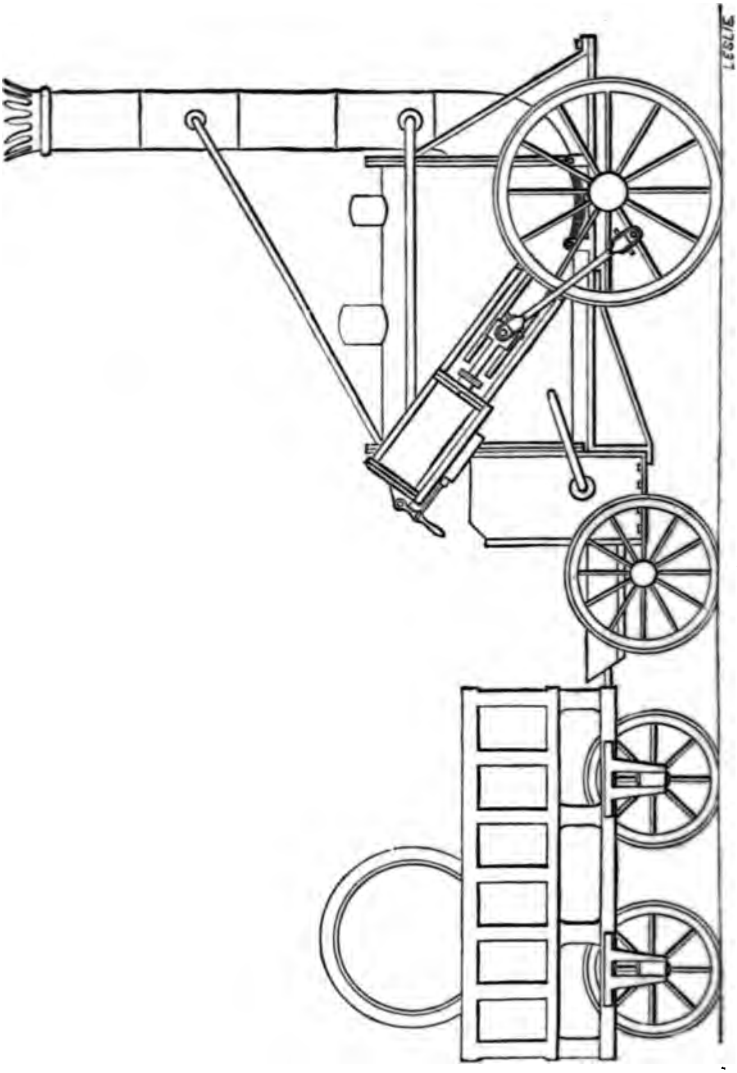


Fig. 64.—Stephenson's Locomotive 'Rocket,' 1830.

Q. What other engines were introduced at this time?

A. There was a very elegant engine by Ericsson, and a very well-designed engine by Mr. Kennedy, who had now joined Edward Bury, of Liverpool, as a manufacturer of steam engines. Mr. Kennedy's engine is represented in fig. 65. But this engine was not a competitor at the trial of locomotives. It had horizontal cylinders, cranked axles, and inside framing, and it was set to work on the Liverpool and Manchester Railway on July 22, 1830. An example of Bury's locomotive, as made about 1840, is given in fig. 66.

Q. Had Ericsson's locomotives small tubes and a steam jet?

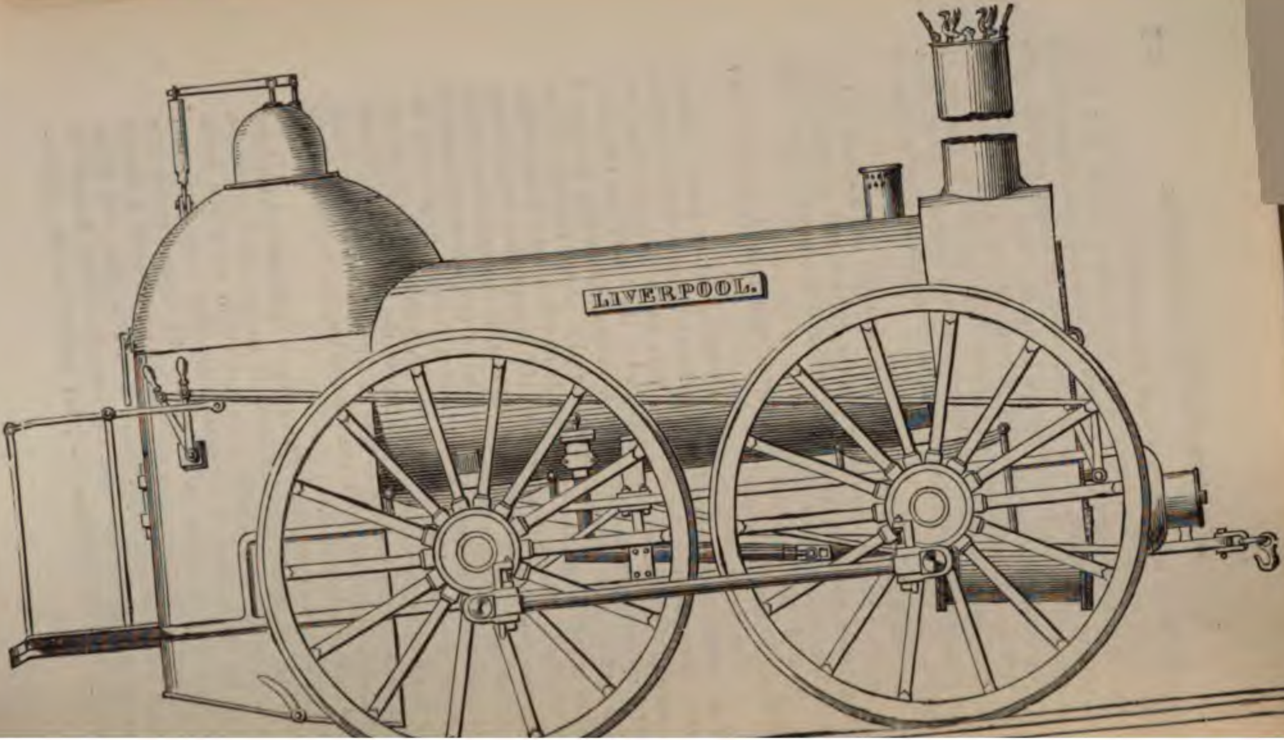
A. No; the air was blown into the furnace, and the products of combustion were conducted through a diminishing copper tube until they entered the chimney.

Q. Will you describe the more important features of the ordinary locomotive engine?

A. The locomotive, as usually constructed to draw carriages upon railways, consists of a cylindrical boiler filled with brass tubes, through which the hot air passes on its progress from the furnace to the chimney; and attached to the boiler are two horizontal cylinders fitted with pistons, valves, connecting rods, and other necessary apparatus to enable the power exerted by the pistons to turn round the cranked axle to which the driving wheels are attached. There are, therefore, two independent engines entering into the composition of a locomotive, the cranks of which are set at right angles with one another, so that when one crank is at its dead point, the other crank is in a position to act with its maximum efficacy. The driving wheels, which are fixed on the crank shaft and turn round with it, propel the locomotive forward on the rails by the mere adhesion of friction, and this is found sufficient, not merely to move the locomotive, but to draw a long train of carriages behind it.

Q. Are locomotive engines condensing or high-pressure engines?

A. They are invariably high-pressure engines, as it would be impossible, or at least highly inconvenient, to carry the water necessary for the purpose of condensation. The steam, therefore, after it has urged the piston to the end of the stroke, escapes into the atmosphere. In locomotive engines the waste steam is always discharged into the chimney through a vertical pipe, and by its rapid passage it greatly increases the intensity of the draught in the chimney, whereby a smaller fire-grate suffices for the combus-


LIVERPOOL.

tion of the fuel, and the evaporative power of the boiler is much increased.

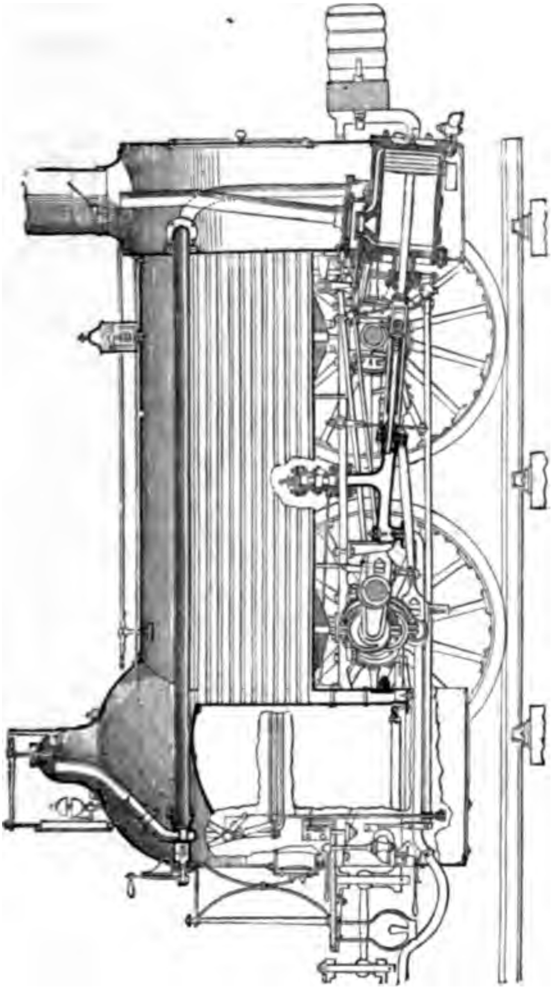


Fig. 66. - Bury's Locomotive Engine, 1840.

Q. Can you give an example of a locomotive engine of the usual form, as constructed about this time?

A. To do this I will take the example of one of Stephenson's locomotive engines with six wheels, represented in fig. 67, as con-

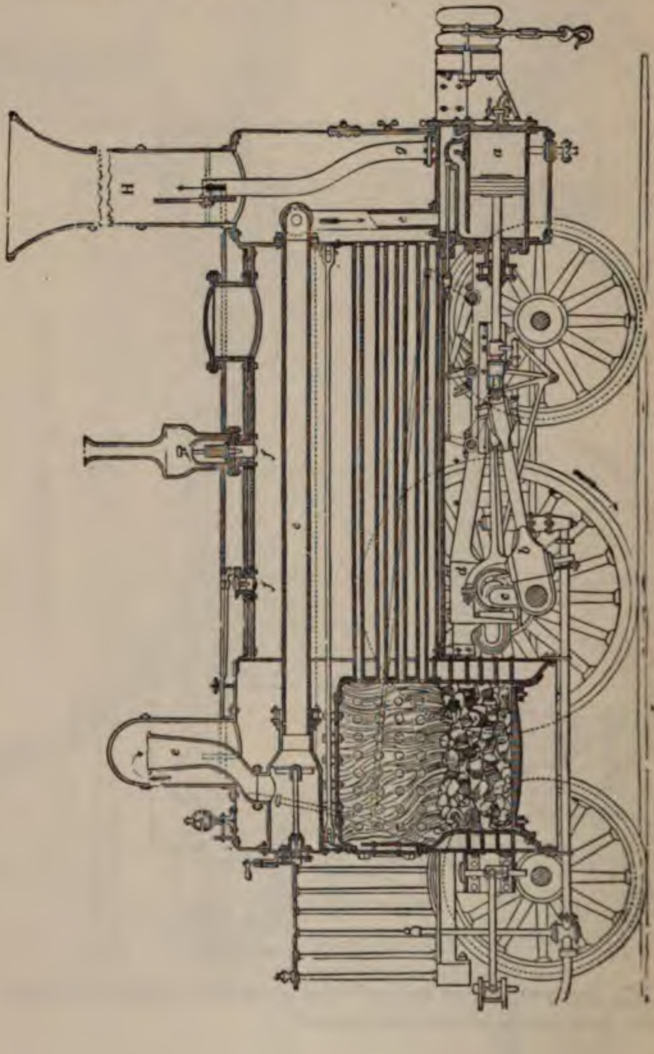


Fig. 67.—Stephenson's Locomotive Engine, 1838.

structed in 1838. *a* is the cylinder, *b* the connecting rod, *c* the crank, *d* the eccentric by which the slide valve is moved; *eee* is the steam pipe by which the steam is conducted from the steam dome of the boiler to the cylinder. Near the furnace end of this pipe is a valve or regulator moved by a handle at the front of the boiler, and of which the purpose is to regulate the admission of the steam to the cylinder; *ff* are safety valves kept closed by springs; *g* is the eduction pipe, or, as it is commonly termed in locomotives, the *blast pipe*, by which the steam, escaping from the cylinder after the stroke has been performed, is projected up the chimney H. The water in the boiler of course covers the tubes, and also the top of the furnace or fire-box. The position of the water surface is shown by a dotted line. It will be understood that there are two engines in each locomotive, though, from the figure being given in section, only one engine can be shown. The cylinders of this engine are each 12 inches diameter; the length of the stroke of the piston is 18 inches, and the diameter of the driving wheel is 5 feet.

Q. What is the tender of a locomotive?

A. It is a carriage attached to the locomotive, of which the purpose is to contain coal for feeding the furnace, and water for replenishing the boiler.

Q. Can you give examples of more modern locomotives, and of greater power?

A. The most recent locomotives resemble in their material features the locomotive represented in fig. 67. Fig. 68 represents Gooch's express engine, adapted for the wide gauge of the Great Western Railway; and Fig. 69 represents Crampton's express engine, adapted to the ordinary or narrow gauge railways. The cylinders of Gooch's engine are each 18 inches diameter, and 24 inches stroke; the driving wheels are 8 feet in diameter; the fire-grate contains 21 square feet of area; and the heating surface of the fire-box is 153 square feet. There are in all 305 tubes in the

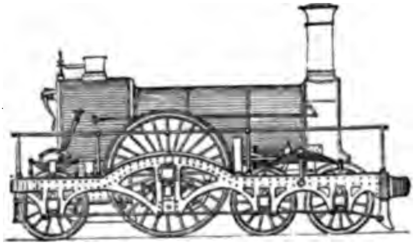


Fig. 68.—Gooch's Locomotive Engine; for the Wide Gauge.

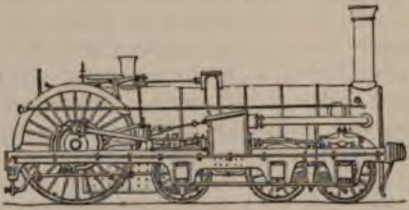


Fig. 69.—Crampton's Locomotive Engine; for the Narrow Gauge.

boiler, each of 2 inches diameter, giving a heating surface in the tubes of 1,799 square feet. The total heating surface, therefore, is 1,952 square feet. An engine of this class will evaporate from 300 to 360 cubic feet of water in the hour, and will convey a load of 236 tons at a speed of 40 miles an hour, or a load of 181 tons at a speed of 60 miles an hour. The weight of this engine empty is 31 tons; of the tender 8½ tons; and the total weight of the engine when loaded is 50 tons. In Crampton's locomotive, the 'Liverpool,' the cylinders were of 24 inches diameter and 18 inches stroke; the driving wheels were 8 feet in diameter; the fire-grate contained 21½ square feet of area, and the heating surface of the fire-box 154 square feet. There were in all 300 tubes in the boiler of 2$\frac{3}{16}$ inches external diameter, giving a surface in the tubes of 2,136 square feet, and a total heating surface of 2,290 square feet. The weight of this engine is stated to be 35 tons, when ready to proceed on a journey. Both engines were displayed at the Great Exhibition in 1851, as examples of the most powerful locomotive engines then made. But Crampton's engines have never come into use in this country. The weight of such engines is very injurious to the railway—bending, crushing, and disturbing the rails, and trying very severely the whole of the railway works. No doubt the weight might be distributed upon a greater number of wheels; but if the weight resting on the driving wheels be much reduced, they will not have sufficient bite upon the rails to propel the train without slipping. This, however, is only one of the evils which the demand for high rates of speed has produced. The width of the railway, or, as it is termed, the *gauge* of the rails, being in most of the railways in this kingdom limited to 4 feet 8½ inches, a corresponding limitation is imposed on the diameter of the boiler, which in its turn restricts the number of the tubes which can be employed. As, however, the attainment of a high rate of speed requires much power, and consequently much heating surface in the boiler, and as the number of tubes cannot be increased without reducing their diameter, it has become necessary, in the case of powerful engines, to employ tubes of a small diameter and of a great length, to obtain the necessary quantity of heating surface ; and such tubes require a very strong draught in the chimney to make them effective. With a draught of the usual intensity, the whole of the heat will be absorbed in the portion of the tube nearest the fire-box, leaving that portion nearest the smoke-box nothing to do but to transmit the smoke ; and with long tubes of small diameter, therefore, a very strong draught is indispensable. In the London Exhibition of 1862, and in the Paris Exhibition of 1867, many locomotives of great power were shown. But most of the heavy engines there exhibited were mere monstrosities, and their use has not been persisted in. Steel rails are now being introduced universally on railways. The tires of railway wheels are now made of steel rolled out without a weld ; and coal is employed instead of coke to generate the steam. In America petroleum is generally used for lubrication, and it should be fed into the cylinders by self-acting means to lubricate the pistons and valves.

LOCOMOTIVES AT THE PARIS EXHIBITION.

Q. Will you give some particulars of the locomotives brought together for exhibition at Paris in 1867?

A. Of these engines the best were the English, the next best were the Belgian, then came the German, and last of all the French. The best examples of engines exhibited were Stephenson's passenger engine, and Kitson's goods engine for the Belgian railways. These engines are shown in figs. 70 and 71.

Q. What are the chief dimensions of Stephenson's engine?

A. Length of grate, 4 feet ; width of grate, 3 feet 5·61 inches ; total grate surface, 13¾ square feet ; height of crown of fire-box above fire-bars, 4 feet 10·8 inches ; capacity of fire-box, 69 cubic feet ; number of tubes, 161 ; length of tubes between tube-plates, 11 feet 4 inches ; external diameter of tubes, 2 inches ; thickness of tubes, ·08 to ·13 inches ; heating surface of tubes, 960 square feet ; heating surface of fire-box, 83 square feet ; total heating surface, 1,043 square feet ; mean diameter of body of boiler, 4 feet ; thickness of plate, ·47 inch ; working pressure permitted, 12¾ atmospheres ; cubic feet of water contained in boiler (3 inches over crown of fire-box), 88·6 cubic feet ; amount of steam space in boiler, 50 cubic feet ; length of smoke-box, 2 feet 8½ inches ; width of smoke-box, 3 feet

11 inches; internal diameter of funnel, 14½ inches; diameter cylinders, 16 inches; stroke, 22 inches; number of wheels, 6; c meter of driving wheels, 6½ feet; total weight of locomotive, emp 27 tons 9 cwt.; total weight, working, 30 tons 9 cwt.; tractive fo

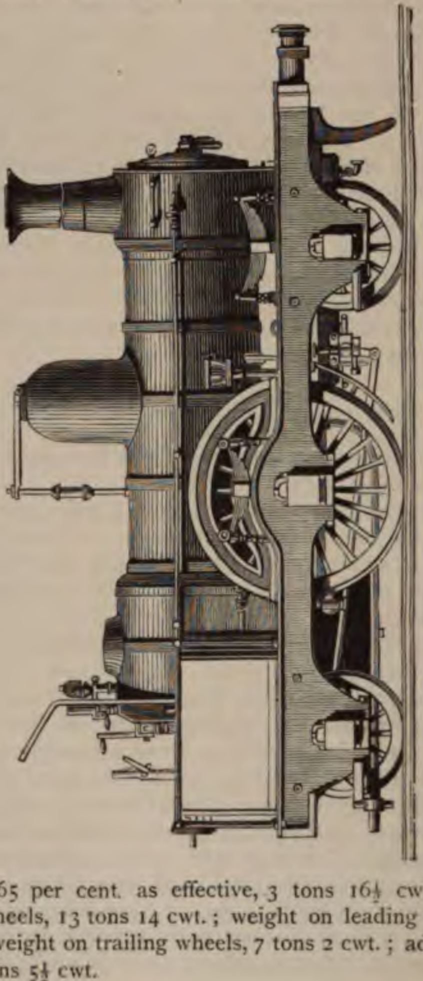


Fig. 70.—Stephenson's Passenger Engine (Paris, 1867).

counting 65 per cent. as effective, 3 tons 16¼ cwt.; weight driving wheels, 13 tons 14 cwt.; weight on leading wheels, 9 t 13 cwt.; weight on trailing wheels, 7 tons 2 cwt.; adhesion at c sixth, 2 tons 5½ cwt.

Q. What are the particulars of Kitson's goods engine, to which have referred?

A. The engine is similar to Stephenson's, the main difference ng in the wheels, which are of smaller diameter, and the six

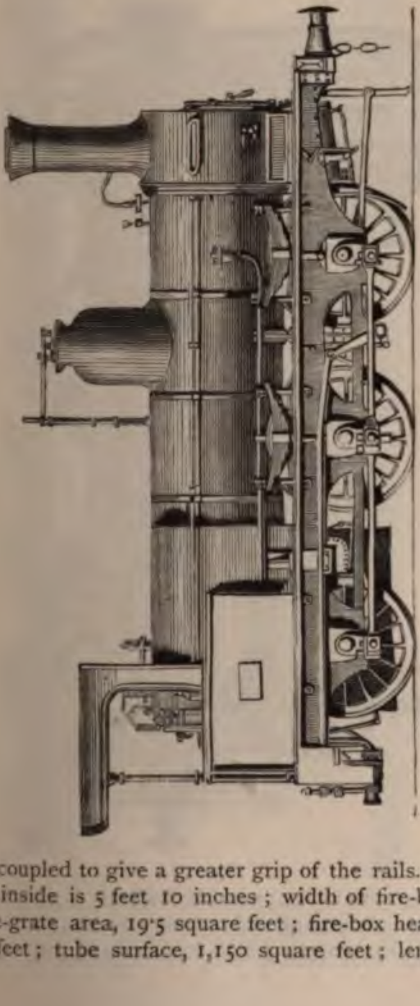


Fig. 71.—Kitson's Goods Locomotive for the Belgian Railway (Paris, 1867).

eels are coupled to give a greater grip of the rails. The length fire-box inside is 5 feet 10 inches; width of fire-box, 3 feet 7¼ hes; fire-grate area, 19·5 square feet; fire-box heating surface, square feet; tube surface, 1,150 square feet; length of tubes

between plates, 12 feet 2½ inches; number of tubes, 200; extern
diameter, 2 inches; diameter of barrel of boiler, 4 feet 6 inches
working pressure, 116 lbs.; diameter of cylinders, 17·5 inches

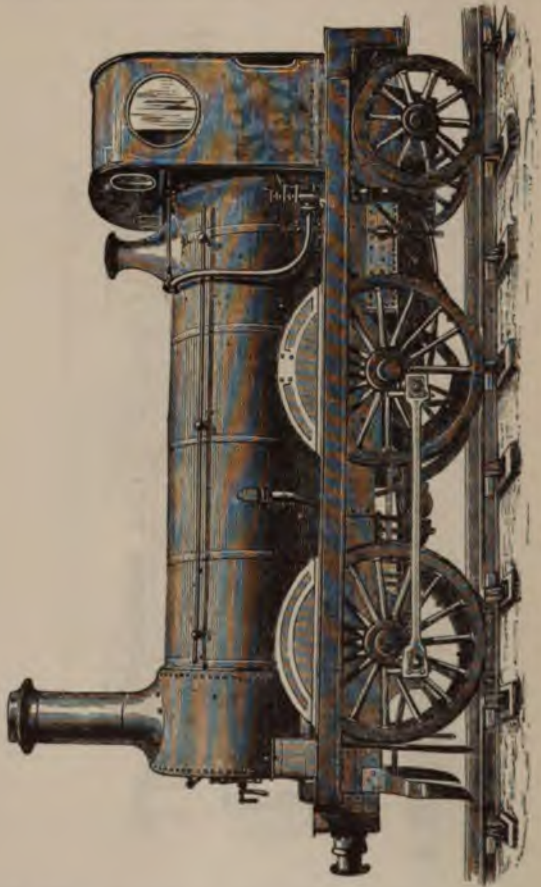


Fig. 79.—Goods Engine, Glasgow and South Western Railway.

length of stroke, 25·25 inches; number of wheels, 6; number couple
6; distance between leading and trailing wheels, 12 feet 5·5 inches
diameter of all the wheels, 4 feet 8·75 inches; total weight, ful

36 tons ; weight on each pair of driving wheels, 12 tons ; total weight, empty, 31·5 tons ; adhesion at one-sixth, 6 tons.

Q. What other locomotives were there deserving attention?

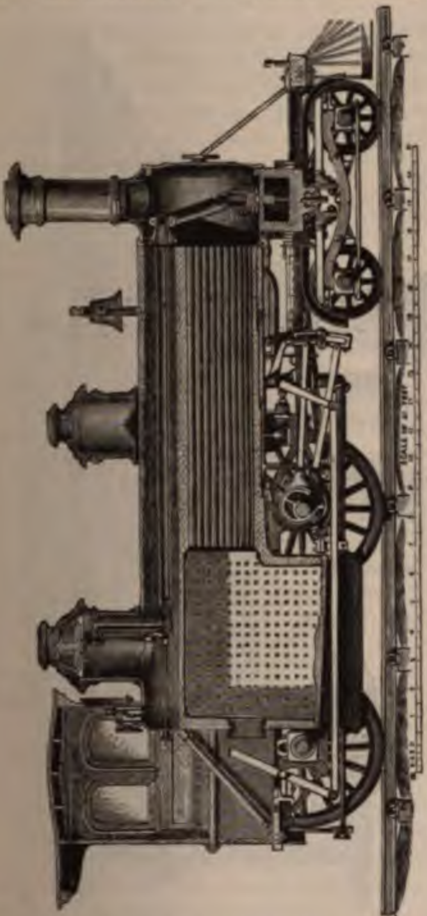


Fig. 73.—Vertical Section of American Locomotive at the Paris Exhibition, 1867.

A. There was a locomotive constructed by Messrs. Hawthorn for the Glasgow and South Western Railway, an American locomotive, and a locomotive for the Copiapo Railway, intended to burn wood, and fitted with a spark-catcher. These engines are represented in figs. 72, 73, and 74. In fig. 70 the diameter of cylinder is 16 inches; length of stroke, 22 inches; area of fire-grate,

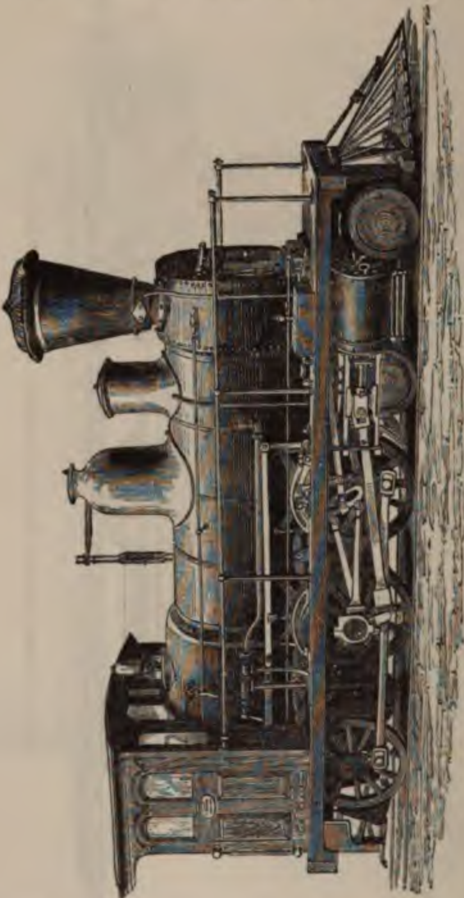


Fig. 74.—Coupled Goods Engine for Copiapo Extension Railway.

13·33 square feet; heating surface of boiler, 930 square feet; sectional area through tube ferrules, 1·986 square feet. The tubes are brass, of 1 wire gauge, and 14 wire gauge at smoke-box, and fixed with steel ferrules at fire-box end only ; barrel of boiler, 4 feet diameter ; and thickness of plate, $\frac{7}{16}$ inch.

Q. What were the chief dimensions of the American locomotive?

A. This engine had the cylinders outside the framing. Diameter of cylinders, 16 inches ; length of stroke, 12 inches ; number of tubes, 142 ; diameter of tubes, 2 inches ; length of tubes, 10 feet 11 inches ; total weight of engine, 27½ tons ; total heating surface, 950 square feet ; total grate surface, 16 square feet ; outside diameter of barrel, 4 feet ; diameter of driving wheels, 5 feet 7 inches. The front part of the engine rests upon a short swivelling carriage, or bogie, and the four wheels which bear the chief part of the weight are coupled.

Q. What are the particulars of the engine for the Copiapo Railway?

A. This engine is a goods engine, with outside cylinders, constructed by Messrs. Hawthorn on the American model, with 6 coupled driving wheels and a bogie. Cylinders, 16 inches diameter, and 24 inches stroke ; area of fire-grate, 15·77 square feet ; area of heating surface, 1,102 square feet ; tubes of brass fixed in with ferrules to every tube at fire-box end, and to every sixth tube at smoke-box end ; barrel of boiler, 4 feet 2 inches diameter. The spark-catcher consists of an inverted basin, which deflects the sparks downwards into a conical casing, while the smoke passes away without obstruction, the momentum of the sparks carrying them downwards, and so separating them from the smoke.

Q. What are the comparative merits of outside and inside cylinders?

A. Outside cylinders superseded the necessity of employing cranked axles, which were long a source of trouble and weakness in locomotives. They also made the essential parts of the engine more accessible, and simplified its structure in some respects. But whereas inside cylinders, being set in the smoke-box, were kept always hot by the passing smoke and red hot cinders, outside cylinders were without any such aid to the maintenance of their temperature, and were consequently more wasteful in fuel. The action of the steam in the two classes of engines was first distinctly traced by Mr. D. K. Clark, and published in his valuable work on Railway Machinery about 1850.

Q. What did Mr. D. K. Clark ascertain?

A. He found that the steam at its first entrance into a cold cylinder was condensed, and that this action of the refrigerating surfaces continued until they became as hot as the steam. There thence followed heated surfaces, and water resulting from the condensation of the steam by which the surfaces had been heated. When the eduction passage was opened the steam escaped, and the water left within the cylinder was re-evaporated by the heated surfaces and escaped also as steam. But the act of re-evaporation again cooled the surfaces, and caused them to again condense a portion of the steam which entered at the next stroke. This action became more pernicious the higher the rate of expansion that was used; and in railway lines using outside cylinders, the drivers did not find any advantage in cutting off the steam sooner than two-thirds of the stroke, leaving one-third to be accomplished by expansion. No doubt the evil is less pronounced in locomotives than in ordinary land engines of the old type, from the high speed at which locomotives are worked, and which does not give time for the heating and cooling to be carried on to the same extent.

Q. The evil seems to be analogous, though less in degree, to that existing in the Newcomen engine, where the cylinder was alternately heated by the steam and cooled by the injection?

A. Yes; and the alleviation is to be found in the same expedient of introducing a little air into the steam before it enters the cylinder, which will hinder the naked contact of the steam by clothing the internal surfaces with a film of air.

CHAPTER II.

POWER AND PERFORMANCE OF ENGINES AND BOILERS.

HORSES-POWER.

Q. You have already stated that a horse-power is 33,000 lbs. raised one foot high in the minute. Why was this standard adopted?

A. This standard was adopted by Mr. Watt as the average force exerted by the strongest London horses, to enable him to determine the relation between the power of a certain size of engine and the power of a horse, so that when it was desired to supersede the use of horses by the erection of an engine, he might, from the number of horses employed, determine the size of engine that would be suitable for the work.

Q. Then, when we talk of an engine of 200 horse-power, it is meant that the impelling efficacy is equal to that of 200 horses, each lifting 33,000 lbs. one foot high in a minute?

A. No, not necessarily. Such was the case in Watt's engines, but the pressure of the steam upon the piston has been increased since his time, so that what is called a 200 horse-power engine by his standard of size exerts, almost in every case, a greater power than was exerted in Watt's time, and a horse power, in the popular sense of the term, became a mere conventional unit for expressing a certain size of engine without reference to the power exerted.

Q. Then each nominal horse-power of a modern engine may raise much more than 33,000 lbs. one foot high in a minute?

A. Yes; some raise 52,000 lbs., others 60,000 lbs., and others 66,000 lbs., one foot high in the minute by each nominal horse-power. Some engines indeed work as high as eight times above the nominal power, and therefore no comparison can be made between the performances of different engines, unless the power actually exerted be first discovered. There were therefore two standards: the actual power exerted, and the nominal power. This last was a mere expression of size, and so much confusion was introduced that nominal power is now being discarded.

Q. How is the power actually exerted by engines ascertained?

A. By means of an instrument called the indicator, which is a miniature cylinder and piston attached to the cylinder cover of the main engine, and which indicates, by the pressure exerted on a spring, the amount of pressure or vacuum per square inch existing within the cylinder. Multiply the area of the piston in square inches by this pressure, and by the motion of the piston, in feet per minute, and divide by 33,000; the quotient is the actual number of horses power of the engine.

Q. How is the nominal power of an engine ascertained?

A. Since the nominal power is a mere conventional expression, it is clear that it must be determined by a merely conventional process. The nominal power of ordinary condensing engines may be ascertained by the following rule: Multiply the square of the diameter of the cylinder in inches by the velocity of the piston in feet per minute, and divide the product by 6,000; the quotient is the number of nominal horses power. In using this rule, however, it is necessary to adopt the speed of piston prescribed by Mr. Watt, which varies with the length of the stroke. The speed of piston with a 2 feet stroke is, according to his system, 160 ft. per minute: with a 2 feet 6 inch stroke, 170; 3 feet, 180; 3 feet 6 inches, 189; 4 feet, 200; 5 feet, 215; 6 feet, 228; 7 feet, 245; 8 feet, 256 ft.

Q. Does not the speed of the piston increase with the length of the stroke?

A. It does: the speed of the piston, according to Watt's standard, varies nearly as the cube root of the length of the stroke.

Q. And may not, therefore, some multiple of the cube root of the length of the stroke be substituted for the velocity of the piston in determining the nominal power?

A. The substitution is quite practicable, and will accomplish some simplification, as the speed of piston proper for the different lengths of stroke cannot always be remembered. The rule for the nominal power of condensing engines when thus considered will be as follows: Multiply the square of the diameter of the cylinder in inches by the cube root of the stroke in feet, and divide the product by 47; the quotient is the number of nominal horses power of the engine, supposing it to be of the ordinary condensing description. This rule assumes the existence of a uniform effective pressure upon the piston of 7 lbs. per square inch. Mr. Watt estimated the effective pressure upon the piston of his 4 horse-power engines at 6·8 lbs. per square inch, and the pressure increased slightly with the power, and became 6·94 lbs. per square inch in engines of 100 horse-power; but it appears to be more convenient to take a uniform pressure of 7 lbs. for all powers. Small engines, indeed, are somewhat less effective in proportion than large ones, but the difference can be made up by slightly increasing the pressure in the boiler; and small boilers will bear such an increase without inconvenience.

Q. How do you ascertain the power of high-pressure engines?

A. The actual power is readily ascertained by the indicator, by the same process as that by which the actual power of low-pressure engines is ascertained.

Q. But how do you ascertain the nominal horse-power of high-pressure engines?

A. The nominal horse-power of a high-pressure engine has never been defined, and it is better that it should not be, as to do this would only be to multiply confusion. The speed of Watt's engine was about 128 times the cube root of the stroke.

Q. Is 128 times the cube root of the stroke in feet per minute the ordinary speed of all engines?

A. Locomotive engines travel at a far quicker speed—an innovation brought about not by any process of scientific deduction but by the accidents and exigencies of railway transit. Most land condensing engines, however, travel at about the speed of 128 times the cube root of the stroke in feet; but many marine condensing engines of recent construction travel at as high a rate as 700 feet per minute. To mitigate the shock of the air pump valves in cases in which a high speed has been desirable, as in the case of marine engines employed to drive the screw propeller without intermediate gearing, india-rubber discs, resting on a perforated metal plate, are now generally adopted; but the india-rubber should be very thick, and the guards employed to keep the discs down should be of the same diameter as the discs themselves, and should permit but little lift.

Q. Can you suggest any eligible method of enabling condensing engines to work satisfactorily at a high rate of speed?

A. One most effective way of enabling condensing or other engines to work satisfactorily at a high speed, lies in the application of balance weights to the engine, so as to balance the momentum of its moving parts, and the engine must also be made very strong and rigid. In the case of engines condensing by jet, it appears to be advisable to perform the condensation partly in the air pump, instead of altogether in the condenser, as a better vacuum and a superior action of the air-pump valves will thus be obtained. Engines constructed upon this plan may be driven at four times the speed of common engines, whereby an engine of large power may be purchased for a very moderate price, and be capable of being put into a very small compass; while the motion, from being more equable, will be better adapted for most purposes for which a rotary motion is required.

Q. Then, if by this modification of the engine you enable it to work at four times the speed, you also enable it to exert four times the power?

A. Yes; always supposing it to be fully supplied with steam.

Q. The high speed engine does not require so heavy a fly wheel as common engines?

A. No; the fly wheel will be lighter, both by virtue of its greater velocity of rotation, and because the impulse communicated by the piston is less in amount and more frequently repeated, so as to approach more nearly to the condition of a uniform pressure.

Q. Can nominal be transformed into actual horse-power?

A. No; that is not possible in the case of common condensing engines. The actual power exerted by an engine cannot be deduced from its nominal power, neither can the nominal power be deduced from the power actually exerted, or from anything else than the dimensions of the cylinder. The actual horse-power being a dynamical unit, and the nominal horse-power a measure of capacity of the cylinder, are obviously incomparable things.

Q. That is, the *nominal* power is a commercial unit by which engines were bought and sold, and the *actual* power a scientific unit by which the quality of their performance was determined?

A. Yes; the nominal power is as much a commercial measure as a yard or a bushel, and is not a thing to be ascertained by any process of science, but to be fixed by authority in the same manner as other measures. The actual power, on the contrary, is a mechanical force or dynamical effort capable of raising a given weight through a given distance in a given time, and of which the amount is ascertainable by scientific investigation. But nominal power, even as a commercial standard, is dying out, and need not now be held as of much account.

Q. Is there any other measure of an actual horse-power than 33,000 lbs. raised one foot high in the minute?

A. There cannot be any *different* measure, but there are several equivalent measures. Thus the evaporation of a cubic foot of water in the hour, or the expenditure of 33 cubic feet of low-pressure steam per minute, was reckoned equivalent to an actual horse-power in Watt's engines, though in modern engines the evaporation of a cubic foot of water in the hour will generate three times that power. 528 cubic feet of water raised one foot high in the minute involves the same result.

DUTY OF ENGINES AND BOILERS.

Q. What is meant by the duty of an engine?

A. The work done in relation to the fuel consumed.

Q. And how is the duty ascertained?

A. In ordinary mill or marine engines it can only be ascertained by the indicator or dynamometer, as the load upon such engines is variable, and cannot readily be determined; but in the case of engines for pumping water, where the load is constant, the number of strokes performed by the engine will represent the work done, and the amount of work done by a given quantity of coal represents the duty. In Cornwall the duty of an engine is expressed by the number of milions of pounds raised one foot high by a bushel, or 94 lbs. of Welsh coal. A bushel of Newcastle coal will only weigh 84 lbs.; and in comparing the duty of a Cornish engine with the performance of an engine in some locality where a different kind of coal is used, it is necessary to pay regard to such variations.

Q. Can you tell the duty of an engine when you know its consumption of coal per horse-power per hour?

A. Yes, if the power given be the actual, and not the nominal, power. Divide 166·32 by the number of pounds of coal consumed per actual horse-power per hour; the quotient is the duty in millions of pounds. If you already have the duty in millions of pounds, and wish to know the equivalent consumption in pounds per actual horse-power per hour, divide 166·32 by the duty in millions of pounds: the quotient is the consumption per actual horse-power per hour. The duty of a locomotive engine is expressed by the weight of fuel it consumes in transporting a ton through the distance of one mile upon a railway; but this is a very imperfect method of representing the duty, as the tractive efficacy of a pound of fuel becomes less as the speed of the locomotive becomes greater; and the law of variation is not accurately known.

Q. What amount of power is generated in good engines of the ordinary kind by a given weight of coal?

A. The duty of different kinds of engines varies very much, and there are also great differences in the performance of different engines of the same class. In ordinary rotative condensing engines of good construction 10 lbs. of coal per nominal horse-power per hour was long a common consumption; but such engines exert nearly twice their nominal power, so that the consumption per actual horse-power per hour would be 5 to 6 lbs. Engines working very expansively, however, attain an economy much superior to this. The average duty of the pumping engines in Cornwall was long about 60,000,000 lbs. raised 1 ft. high by a bushel of Welsh coals, which weighs 94 lbs. This is equivalent to a consumption of 3·1 lbs. of coal per actual horse-power per hour; but some engines reached a duty of above 100,000,000, or 1·74 lbs. of coal per actual horse-power per hour. Marine engines now work with a consumption as small as this. Locomotives consume from 8 to 10 lbs. of fuel in evaporating a cubic foot of water.

Q. But is not the evaporative power of locomotives affected materially by the proportions of the boiler?

A. Yes, and this may be said of all boilers; but in locomotive boilers, perhaps, the effect of any misproportion becomes more speedily manifest. A high temperature of the fire-box is found to be conducive to economy of fuel; and this condition, in its turn, involves a small area of grate-bars. The heating surface of locomotive boilers should be about 80 square feet for each square foot of grate-bars, and upon each foot of grate-bars about 1 cwt. of fuel should be burnt in the hour.

Q. Probably the heat is more rapidly absorbed when the temperature of the furnace is high?

A. That seems to be the explanation. The rapidity with which a hot body imparts heat to a colder varies as the square of the difference of temperature; so that if the temperature of the furnace be very high, the larger part of the heat passes into the water at the furnace, thereby leaving little to be transmitted by the tubes. If, on the contrary, the temperature of the furnace be low, a large part of the heat will pass into the tubes, and more tube surface will be required to absorb it. About 16 cubic feet of water should be evaporated by a locomotive boiler for each square foot of fire-grate, which, with the proportion of heating surface already mentioned, leaves 5 square feet of heating surface to evaporate a cubic foot of water in the hour. This is only about half the amount of surface usual in land and marine boilers per cubic foot evaporated, and its small amount is due mainly to the high temperature of the furnace, which, by the rapidity of transmission it causes, is tantamount to an additional amount of heating surface.

THE INDICATOR.

Q. You have already stated that the actual power of an engine is ascertained by an instrument called the indicator, which consists of a small cylinder with a piston moving against a spring, and compressing it to an extent answerable to the pressure of the steam. Will you explain further the structure and mode of using that instrument?

A. The structure of a common form of indicator will be readily apprehended by a reference to fig. 75, which is a section of McNaught's indicator. Upon a movable barrel A, a piece of paper is wound, the ends of which are secured by the slight brass clamps shown in the drawing. The barrel is supported by the bracket *b*, proceeding from the body of the indicator, and at the bottom of the barrel a watch spring is coiled with one end attached to the barrel and the other end to the bracket, so that when the barrel is drawn round by a string wound upon its lower end like a roller blind, the spring returns the barrel to its original position when the string is relaxed. The string is attached to some suitable part of the engine, and at every stroke the string is drawn out, turning round the barrel, and the barrel is returned again by the spring on the return stroke.

Q. But in what way can these reciprocations of the barrel determine the power of the engine?

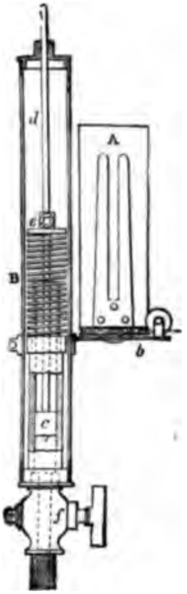


Fig. 75.
McNaught's Indicator.

A. They do not determine it of themselves, but are only part of the operation. *c* is a small piston moving steam-tight in a cylinder, *d* is the piston rod, and *e* a spiral spring of steel, which the piston, when forced upwards by the steam or sucked downwards by the vacuum, either compresses or extends; *f* is a cock attached to the cylinder of the indicator, and which is screwed into the cylinder cover. It is obvious that, so soon as this cock is opened, the piston *c* will be forced up when the space above the piston of the engine is opened to the boiler, and sucked down when that space is open to the condenser—in each case to an extent proportionate to the pressure of the steam or the perfection of the vacuum, the top of the piston *c* being open to the atmosphere. A pencil, with a knife-hinge, is inserted into the piston rod at *e*, and the point of the pencil bears upon the surface of the paper wound upon the drum A. If the drum A did not revolve, this pencil would merely trace on the paper a vertical line; but as the drum A moves round and back again every stroke of the engine, and as the pencil moves up and down again every stroke of the engine, the combined movements trace upon the paper a species of rectangle, which is called an indicator diagram; and the nature of this diagram determines the nature of the engine's performance.

Q. How does it do this?

A. It is clear that if the pencil was moved up instantaneously to the top of its stroke, and was also moved down instantaneously to the bottom of its stroke, and if it remained without fluctuation while at the top and bottom, the figure described by the pencil would be a perfect rectangle, of which the vertical height would represent the total pressure of the steam and vacuum, and therefore the total pressure urging the piston of the engine. But in practice the pencil will neither rise nor fall instantaneously, nor will it remain at a uniform height throughout the stroke. If the steam be worked expansively the pressure will begin to fall so soon as the steam is cut off; and at the end of the stroke, when the steam comes to be discharged, the subsidence of pressure will not be instantaneous, but will occupy an appreciable time. It is clear, therefore, that in no engine can the diagram described by an indicator be a complete rectangle; but the more nearly it approaches to a rectangle the larger will be the power produced at every stroke with any given pressure, and the area of the space included within the diagram will in every case accurately represent the power exerted by the engine during that stroke.

Q. And how is this area ascertained?

A. It may be ascertained in various ways; but the usual mode is to take the vertical height of the diagram at a number of equidistant points on a base line, and then to take the mean of these several heights as representative of the mean pressure actually urging the piston. Now if you have the pressure on the piston per square inch, and if you know the number of square inches in its area, and the velocity with which it moves in feet per minute, you have obviously the dynamical effort of the engine, or, in other words, its actual power.

Q. How is the base line you have referred to obtained?

A. In proceeding to take an indicator diagram, the first thing to be done is to allow the barrel to make two or three reciprocations with the pencil resting against it, before opening the cock attached to the cylinder. There will thus be traced a horizontal line, which is called the *atmospheric line*, and in condensing engines a part of the diagram will be above and a part of it below this line; whereas, in high-pressure engines the whole of the diagram will be above this line. Upon this line the vertical ordinates may be set off at equal distances, or upon any base line parallel to it; but the usual course is to erect the ordinates on the atmospheric line.

Q. Will you give an example of an indicator diagram?

A. Fig. 76 is an indicator diagram taken from a high-pressure engine, and the wavy line *a*, *b*, *c*, forming a sort of irregular parallelogram, is that which is described by the pencil. As there is no vacuum in this engine, the atmospheric line will be below the diagram, and it is represented by the line A B. The scale at the side shows the pressure of the steam per square inch, which in this engine rose to a little over 60 lbs. The steam begins to be cut off

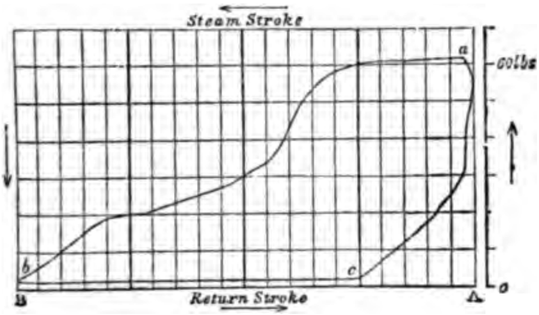


Fig. 76.—Indicator Diagram.

when about one-fourth of the stroke has been performed, and the pressure consequently falls. The rounding away of the right hand corner of the diagram shows that the steam has been compressed on the reverse side of the piston by shutting the valve before the end of the stroke.

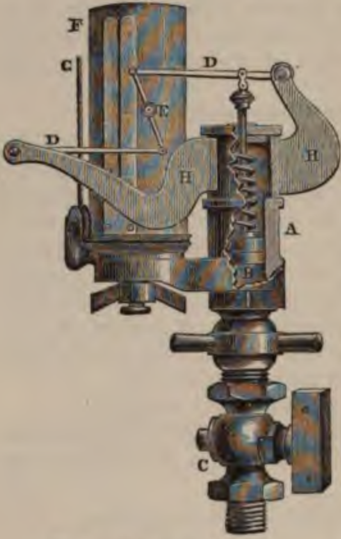


Fig. 77.—Richards' Indicator.

Q. Is there any other form of indicator?

A. Another form, slightly different from McNaught's, and now much used, is that known as Richards', and which is shown in fig. 77. A is the cylinder and B the piston of the instrument, and C is the cock by which it is put into connection with the cylinder of the engine. D D are the arms of a parallel motion intended to compel the pencil E to move up and down vertically. F is the barrel on which the paper is fixed as in McNaught's, and G is the string by which the barrel is moved on its axis. H H are arms to which the parts of the parallel motion are attached. It will be seen from the point at which the piston rod is attached to the parallel motion, that the pencil moves through a much greater length than the piston of the instrument, by which arrangement the momentum is somewhat reduced.

DYNAMOMETER, GAUGES, AND CATARACT.

Q. What other gauges or instruments are there for telling the state, or regulating the power, of an engine?

A. There is the counter for telling the number of strokes the engine makes, and the dynamometer for ascertaining the tractive power of steam vessels or locomotives, or the force with which a shaft rotates. Then there are the gauge cocks, and glass tubes, or floats, for telling the height of water in the boiler; the Bourdon gauge for telling the pressure of the steam or the quality of the vacuum; and in pumping engines there is the cataract for regulating the speed of the engine.

Q. Will you describe the mechanism of the counter?

A. The counter consists of a train of wheelwork, so contrived that by every stroke of the engine an index-hand is moved forward a certain space, whereby the number of strokes made by the engine in any given time is accurately recorded. In most cases the motion is communicated by means of a detent—attached to some reciprocating part of the engine—to a ratchet wheel which gives motion to the other wheels in its slow revolution: but it is preferable to derive the motion from some revolving part of the engine by means of an endless screw, as where the ratchet is used the detent will sometimes fail to carry it round the proper distance. In the counter contrived by Mr. Adie, an endless screw works into the rim of two small wheels situated on the same axis, but one wheel having a tooth more than the other, whereby a differential motion is obtained; and the difference in the velocity of the two wheels, or their motion upon one another, expresses the number of strokes performed. The endless screw is attached to some revolving part of the engine, whereby a rotatory motion is imparted to it; and the wheels into which the screws work hang down from it like a pendulum, and are kept stationary by the action of gravity.

Q. What is the nature of the dynamometer?

A. The dynamometer employed for ascertaining the traction upon railways consists of two flat springs joined together at the ends by links, and the amount of separation of the springs at the centre indicates, by means of a suitable hand and dial, the force of traction. A cylinder of oil with, a small hole through its piston, is sometimes added to this instrument to prevent sudden fluctuations. In screw vessels the forward thrust of the screw is measured by a dynamometer constructed on the principle of a weighing machine for carts, in which a small spring pressure at the index will balance a very great pressure where the thrust is applied; and in each case the variations of pressure are recorded by a pencil on a sheet of paper, carried forward by suitable mechanism, whereby the mean thrust is easily ascertained. The tractive force of paddle wheel steamers is ascertained by a dynamometer fixed on shore, to which the floating vessel is attached by a rope. Sometimes the power of an engine is ascertained by a friction-break dynamometer applied to the shaft.

Q. What will determine the amount of thrust shown by the dynamometer?

A. In locomotives and in paddle steamers it will be determined by the force turning the wheels, and by the smallness of the diameter of the wheels; for with small wheels the thrust will be greater than with large wheels. In screw vessels the thrust will be determined by the force turning round the screw, and by the smallness of the screw's pitch; for with any given force of torsion a fine pitch of screw will give a greater thrust than a coarse pitch of screw, just as is the case when a screw works in a solid nut.

Q. Will you explain the use of the glass gauges affixed to the boiler?

A. The glass gauges are tubes affixed to the fronts of boilers, by the aid of which the height of the water within the boilers is readily ascertainable, for the water will stand at the same height in the tube as in the boiler, with which there is a communication maintained both at the top and bottom of the tube by suitable stopcocks. The cocks connecting the glass tube with the boiler should always be so constructed that the tube may be blown through with the steam, to clear it of any internal concretion that may impair its transparency; and the construction of the sockets in which the tube is inserted should be such that, even when there is steam in the boiler, a broken tube may be replaced with facility.

Q. What, then, are the gauge cocks?

A. The gauge cocks are cocks penetrating the boiler at different heights, and which, when opened, tell whether it is water or steam that exists at the level at which they are respectively inserted. It is unsafe to trust to the glass gauges altogether as a means of ascertaining the water level, as sometimes they become choked, and it is necessary, therefore, to have gauge cocks in addition; but if the boiler be short of steam, and a partial vacuum be produced within it, the glass gauges become of essential service, as the gauge cocks will not operate in such a case, for though opened, instead of steam and water escaping from them, the air will rush into the boiler It is expedient to carry a pipe from the lower end of the glass tube downward into the water of the boiler, and a pipe from the upper end upward into the steam in the boiler, so as to prevent the water from boiling down through the tube, as it might otherwise do, and prevent the level of the water from being ascertainable. The average level of water in the boiler should be above the centre of the tube; and the lowest of the gauge cocks should always run water, and the highest should always blow steam.

Q. Is not a float sometimes employed to indicate the level of the water in the boiler?

A. A float for telling the height of water in the boiler is employed only in the case of land boilers, and its action is like that of a buoy floating on the surface, which, by means of a light rod passing vertically through the boiler, shows at what height the water stands, or, as already explained, opens or shuts a feed valve in some cases. The float is usually formed of stone or iron, and is so counterbalanced as to make its operation the same as if it were a buoy of timber.

Q. What is the present form of cataract which is employed to regulate the speed of pumping engines?

A. An early form of cataract has been already described. The modern form consists of a small pump-plunger and barrel, set in a cistern of water, the barrel being furnished on the one side with a valve opening inwards, through which the water obtains admission to the pump chamber from the cistern, and on the other side with a cock, through which, if the plunger be forced down, the water must pass out of the pump chamber. The engine in the upward stroke of the piston, which is accomplished by the preponderance of weight at the pump end of the beam, raises up the plunger of the cataract by means of a small rod—the water entering readily through the valve already referred to; and when the engine reaches the top of the stroke, it liberates the rod by which the plunger has been drawn up, and the plunger then descends by gravity, forcing out the water through the cock, the orifice of which has previously been adjusted, and the plunger in its descent opens the injection valve, which causes the engine to make a stroke.

Q. Suppose the cock of the cataract be shut?

A. If the cock of the cataract be shut, it is clear that the plunger cannot descend at all, and as in that case the injection valve cannot be opened, the engine must stand still; but if the cock be slightly opened the plunger will descend slowly, the injection valve will slowly open, and the engine will make a gradual stroke as it obtains the water necessary for condensation. The extent to which the cock is open, therefore, will regulate the speed with which the engine works; so that, by the use of the cataract, the speed of the engine may be varied to suit the variations in the quantity of water requiring to be lifted from the mine. In some cases an air cylinder, and in other cases an oil cylinder, is employed instead of the apparatus just described; but the principle on which the whole of these contrivances operate is identical, and the only difference is in the detail.

Q. Has no instrument been contrived to measure and record the power generated by an engine in a given time in the same way in which a gas meter registers the consumption of gas?

A. Yes, there is such an instrument, called a duty meter, but hitherto it has been used to only a very limited extent, though the emulation which would be excited by publishing the duty of different engines would be an important stimulus to increased economy. There are several forms of duty meter. Some are made with a cylinder and piston like those of an indicator. The piston records the pressure at several different parts of the stroke. These different pressures are registered and their mean extracted, and this combined with the number of strokes, also registered, gives the power.

Q. You have shown that the performance of an engine is determinable by the indicator; but how do you determine the power of the boiler?

A. By the quantity of water it evaporates. There are now various forms of water-meter which accurately determine the quantity of water flowing through them; so that the volume of the feed water, and also of the condensing water, may now be readily ascertained.

CHAPTER III.

PROPORTIONS OF BOILERS.

HEATING AND FIRE-GRATE SURFACE.

Q. What are the considerations which must chiefly be attended to in settling the proportions of boilers?

A. In the first place there must be sufficient grate surface to enable the quantity of coal requisite for the production of the steam to be conveniently burnt, taking into account the intensity of the draught; and in the next place there must be a sufficient flue or tube surface readily to absorb the heat thus produced, so that there may be no needless waste of heat by the chimney. The flues or tubes, moreover, must have such an area of cross section, and the chimney must be of such dimensions, as will enable a suitable draught through the fire to be maintained; and the boiler must be made capable of containing such supplies of water and steam as will obviate inconvenient fluctuations in the water-level, and abate the risk of water being carried over into the engine with the steam. With all these conditions the boiler must be as light and compact as possible, and must be so contrived as to be capable of being cleaned and repaired with facility. Finally it must be strong.

Q. Supposing, then, that you had to proportion a boiler, which should be capable of supplying steam sufficient to propel a steam vessel or railway train at a given speed, or to perform any other given work, how would you proceed?

A. I would first ascertain the resistance which had to be overcome, and the velocity with which it was necessary to overcome it. This would give me an expression of the horse-power I must employ. I should then know what pressure and volume of steam were required to generate this power; and, finally, I should allow a sufficient heating and fire-grate surface in the boiler, according to the kind of boiler it was, to furnish the requisite quantity of steam, or, in other words, to evaporate the requisite quantity of water?

Q. Will you state the amount of heating surface and grate surface necessary to evaporate a given quantity of water?

A. The number of square feet of heating or flue surface, required to evaporate a cubic foot of water per hour, is about 70 square feet in Cornish boilers, 8 to 11 square feet in land and marine boilers, and 5 or 6 square feet in locomotive boilers. The number of square feet of heating surface per square foot of fire grate is from 13 to 15 square feet in waggon or other low-pressure land boilers, about 40 square feet in Cornish boilers, and from 50 to 90 square feet in locomotive boilers. About 80 square feet in locomotives is a very good proportion in the case of locomotives using coke. But locomotives now generally use coal, and in them a somewhat larger area of fire grate is found advantageous.

Q. What is the heating surface of boilers per horse-power?

A. About 9 square feet of flue and furnace surface per horse-power was the usual proportion in waggon boilers, reckoning the total surface exposed to the heat as effective surface, if the boilers were of a considerable size; but in the case of small boilers the proportion was larger. The total heating surface of a two horse-power waggon boiler was, according to Boulton and Watt's proportions, 30 square feet, or 15 feet per horse-power; whereas, in the case of a 45 horse-power boiler, the total heating surface was 438 square feet, or 9·6 feet per horse-power. In marine boilers nearly the same proportions obtained. The original boilers of the 'Great Western' steamer, by Messrs. Maudslay, were proportioned with about 10 square feet of flue and furnace surface per nominal horse-power of the engine, reckoning the total amount of surface as effective; but in the boilers of the 'Retribution,' by the same makers, but of larger size, a somewhat smaller proportion of heating surface was adopted. Boulton and Watt found that, in their marine flue boilers, 9 square feet of flue and furnace surface were requisite to boil off a cubic foot of water per hour, which is the proportion of heating surface allowed in their land boilers per horse-power.

Q. If nominal horse-power be, as you have stated, an indefinite quantity, how can heating surface or anything else be reckoned by it?

A. It cannot be with any propriety, but such, nevertheless, was for many years the usual practice, though it was like measuring distances by a mile the length of which was not uniform, and which had also itself to be stated before any just conception of quantity could be reached.

Q. In marine flue boilers, was the whole surface of the flues exposed to the smoke reckoned as effective?

A. The whole of the sides and the whole of the top of the flues were reckoned as effective, but not the bottoms.

Q. What was the proportion of fire grate per horse-power adopted in these boilers?

A. Boulton and Watt allowed 0·64 of a square foot area of grate bars per nominal horse-power in their marine flue boilers, but sometimes so large an area of fire grate could not be conveniently got, and the proportion of half a square foot per nominal horse-power, which was the proportion adopted in the original boilers of the 'Great Western,' seemed to answer very well in engines working with a moderate pressure, and with some expansion; and this proportion was widely adopted. With this allowance, there would be 22 to 24 square feet of heating surface per square foot of fire grate; and if the consumption of fuel were taken at 6 lbs. per nominal horse-power per hour, there would be about 12 lbs. of coal consumed per hour on each square foot of grate. Furnaces should not be more than 5 feet long, as, if much longer than this, it will be impossible to work them properly for any considerable length of time, and they will become choked with clinker at the back ends.

Q. What quantity of fuel was usually consumed per hour, on each square foot of fire grate, in different boilers at the time the marine flue boiler had reached its highest development—say about 1840?

A. The quantity of fuel burned on each square foot of fire grate per hour varied very much in different boilers of that date: in waggon boilers it was from 10 to 13 lbs.; in Cornish boilers from 3½ to 4 lbs.; and in locomotive boilers from 80 to 150 lbs. About 1 cwt. per hour was a good proportion in locomotives.

CALORIMETER AND VENT.

Q. In what manner were the proper sectional area and the proper capacity of the flue of a flue boiler determined?

A. The proper collective area for the escape of the smoke and flame over the furnace bridges in marine boilers was 19 square inches per nominal horse-power, according to Boulton and Watt's practice, and for the sectional area of the flue they allowed 18 square inches per horse-power. The sectional area of the flue in square inches is what is termed the *calorimeter* of the boiler, and the calorimeter divided by the length of the flue in feet is what is termed the *vent*. In marine flue boilers of good construction the vent varied between the limits of 20 and 25, according to the size of the boiler and other circumstances, the largest boilers having generally the largest vents; and the calorimeter divided by the vent gave the length of the flue in feet. The flues of all flue boilers diminished in their calorimeter as they approached the chimney, as the smoke contracts in its volume in proportion as it parts with its heat.

Q. Was the method of determining the dimensions of a boiler flue, by a reference to its vent and calorimeter, the method generally pursued?

A. It was Boulton and Watt's method; but some very satisfactory boilers were made by allowing a proportion of 0·6 of a square foot of fire grate per nominal horse-power, and making the sectional area of the flue at the largest part $\frac{1}{7}$th of the area of fire grate, and at the smallest part, where it entered the chimney, $\frac{1}{11}$th of the area of the fire grate. These proportions were retained whether the boiler were flue or tubular, and from 14 to 16 square feet of tube surface were allowed per nominal horse-power.

Q. Were the proportions of vent and calorimeter, taken by Boulton and Watt for marine flue boilers, found to be applicable also to waggon and tubular boilers?

A. No. In waggon and tubular boilers very different proportions prevailed; yet the proportions proper for every kind of boiler were determinable on the same general principle. In waggon boilers the proportion of the perimeter of the flue, which is effective as heating surface, is to the total perimeter as 1 to 3, or, in some cases, as 1 to 2·5; and with any given area of flue, therefore, the length of the flue must be from 3 to 2·5 times greater than would be necessary if the total surface were effective, else the requisite quantity of heating surface could not be obtained. If then the vent be the calorimeter divided by the length, and the length of flue be made 3 or 2·5 times greater, the vent must become 3 or 2·5 times less; and in waggon boilers, accordingly, the vent varied from 8 to 11 instead of from 21 to 25, as in the case of marine flue boilers. In tubular marine boilers, when they came to be introduced, the calorimeter was usually made only about half the amount allowed by Boulton and Watt for marine flue boilers, or, in other words, the collective sectional area of the tubes for the transmission of the smoke was from 8 to 9 square inches per nominal horse-power.

Q. What were the ordinary dimensions of the flue in waggon boilers?

A. In Boulton and Watt's 45-horse waggon boiler the area of flue was 18 square inches per horse-power; but the area per horse-power increased very rapidly as the size of the boiler became less, and amounted to about 80 square inches per horse-power in a boiler of 2 horse-power. Some such increase was obviously inevitable if a similar form of flue were retained in the larger and smaller powers, and at the same time the elongation of the flue in the same proportion as the increase of any other dimension was prevented; but in the smaller class of waggon boilers the consideration of facility of cleaning the flues was also operative in inducing a large proportion of sectional area. Boulton and Watt's 2 horse-power waggon boiler had 30 square feet of surface, and the flue was 18 inches high, above the level of the boiler bottom, by 9 inches wide; while their 12-horse waggon boiler had 118 square feet of heating surface, and the dimensions of the flue similarly measured were 36 inches by 13 inches. The width of the smaller flue, if similarly proportioned to the larger one, would have been 6½ inches instead of 9 inches, and, by assuming this dimension, we should have the same proportion of sectional area per square foot of heating surface in both boilers. The length of flue in the 2-horse boiler was 19·5 feet, and in the 12-horse boiler 39 feet, so that the length and height of the flue were increased in the same proportion. These proportions, all carefully settled under Mr. Watt's direction, are still useful and instructive, though the waggon boiler itself is now obsolete.

Q. Will you give an example of the proportions of a flue in the case of a marine boiler?

A. The 'Nile' steamer, with engines of 110 horse-power nominal, by Boulton and Watt, was supplied with steam by two boilers, which were therefore of 55 horse-power each. The height of the flue winding within the boiler was 60 inches, and its mean width 16½ inches, making a sectional area or calorimeter of 990 square inches, or 18 square inches per horse-power of the boiler.

The vent of the flue was 39 feet, making the vent 25, which was the vent proper for large boilers. In the 'Dee' and 'Solway' steamers, by Scott and Sinclair, the calorimeter was only 9·72 square inches per horse-power; in the 'Eagle,' by Caird, 11·9; in the 'Thames' and 'Medway,' by Maudslay, 11·34, and in a great number of other cases it did not rise above 12 square inches per horse-power; but the engines of most of these vessels were intended to operate to a certain extent expansively, and the boilers were less powerful in evaporating efficacy on that account.

Q. Then the chief difference in the proportions established by Boulton and Watt, and those followed by the other manufacturers you have mentioned, was that Boulton and Watt set a more powerful boiler to do the same work?

A. That is the main difference. The proportion which one part of the boiler bears to another part is very similar in the cases cited; but the proportion of boiler relatively to the size of the engine varies very materially. Thus, the calorimeter *of each boiler* of the 'Dee' and 'Solway' was 1,296 square inches; of the 'Eagle,' 1,548 square inches; and of the 'Thames' and 'Medway,' 1,134 square inches; and the lengths of flue were 57, 60, and 52 feet in the boilers respectively, which made the respective vents 22½, 25, and 21. Taking then the boiler of the 'Eagle' for comparison with the boiler of the 'Nile,' as it had the same vent, it will be seen that the proportions of the two are almost identical, for 990 is to 1,548 as 39 is to 60, nearly; but Messrs. Boulton and Watt would not have set a boiler like that of the 'Eagle' to do so much work.

Q. Then the evaporating power of the boiler varied as the sectional area of the flue?

A. The evaporating power varied as the square root of the area of the flue, if the length of the flue remained the same; but it varied as the area simply, if the length of the flue were increased in the same proportion as its other dimensions. The evaporating power of a boiler, other things being the same, is referable to the amount of its heating surface, and the amount of heating surface in any flue or tube is proportional to the product of the length of the tube and the square root of its sectional area, multiplied by a certain quantity that is constant for each particular form. But in similar tubes the length is proportional to the square root of the sectional area; therefore, in similar tubes, the amount of heating surface is proportional to the sectional area. On this area also depends the quantity of hot air passing through the flue, supposing the intensity of the draught to remain unaffected, in which case the quantity of hot air or smoke passing through the flue should vary in the same ratio as the quantity of surface.

Q. A boiler, therefore, to exert four times the power, should have four times the extent of heating surface, and four times the sectional area of flue for the transmission of the smoke?

A. Yes; and if the same form of flue is to be retained, it should be of twice the diameter and twice the length; or twice the height and width if rectangular, and twice the length. As, then, the diameter or square root of the area increases in the same ratio as the length, the square root of the area divided by the length ought to be a constant quantity in each type of boiler, in order that the same proportions of flue may be retained; and in waggon boilers without an internal flue, the height in inches of the flue encircling the boiler divided by the length of the flue in feet will be 1, very nearly. Instead of the square root of the area, the effective perimeter, or outline of that part of the cross section of the flue which is effective in generating steam, may be taken; and the effective perimeter divided by the length ought to be a constant quantity in similar forms of flue and with the same velocity of draught, whatever the size of the flue may be.

Q. Will this proportion alter if the form of the flue be changed?

A. It is clear that, with any given area of flue, to increase the perimeter by adopting a different shape is tantamount to a diminution of the length of the flue; and, if the perimeter be diminished, the length of the flue must at the same time be increased, else it will be impossible to obtain the necessary amount of heating surface. In Boulton and Watt's waggon boilers the sectional area of the flue in square inches per square foot of heating surface was 5·4 in the 2-horse boiler; in the 3-horse it was 4·74; in the 4-horse, 4·35; 6-horse, 3·75; 8-horse, 4·33; 10-horse, 3·96; 12-horse, 3·63; 18-horse, 3·17; 30-horse, 2·52; and in the 45-horse boiler, 2·05 square inches. Taking the amount of heating surface in the 45-horse boiler at 9 square feet per horse-power, we obtain 18 square inches of sectional area of flue per horse-power, which was also Boulton and Watt's proportion of sectional area for marine boilers with internal flues.

Q. If to increase the perimeter of a flue is virtually to diminish the length, then a tubular boiler, where the perimeter is in effect greatly extended, ought to have but a short length of tube?

A. The flue of the 'Nile' steamer, if reduced to the cylindrical form, would be 35½ inches in diameter to have the same area; but it would then require to be made 47¾ feet long to have the same amount of heating surface, excluding the bottom as non-effective. Supposing that with these proportions the heat was sufficiently extracted from the smoke, then every tube of a tubular boiler in which the same draught existed ought to have very nearly the same proportions.

Q. But what are the best proportions of the parts of tubular boilers relatively with one another?

A. The proper relative proportions of the parts of tubular boilers may easily be ascertained by a reference to the settled proportions of flue boilers; for the same general principles are operative in both cases. In the 'Nile' steamer each boiler of 55 horse-power had about 497 square feet of flue surface, or 9 square feet per horse-power, reckoning the total surface as effective. The area of the flue, which was rectangular, was 990 square inches, therefore the area was equal to that of a tube 35½ inches in diameter; and such a tube, to have a heating surface of 497 square feet, must be 53·4 feet or 640·8 inches in length. The length, therefore, of the tube would be about 18 times its diameter, and with the same velocity of draught these proportions must obtain, whatever the absolute dimensions of the tube may be. With a calorimeter, therefore, of 18 square inches per horse-power, the length of a tube 3 inches diameter should not exceed 4 feet 6 inches, since the heat would be sufficiently extracted from the smoke in this length, if the smoke only travelled at the velocity due to a calorimeter of 18 square inches per horse-power.

Q. Is this, then, the maximum length of flue which can be used in tubular boilers with advantage?

A. By no means. The tubes of tubular boilers are almost always more than 4 feet 6 inches long, but then the calorimeter is almost always less than 18 square inches per horse-power—generally about two-thirds of this. Indeed, tubular boilers with a large calorimeter are not found to be so satisfactory as where the calorimeter is smaller, partly from the propensity of the smoke in such cases to pass through a few of the tubes instead of the whole of them, and partly from the deposit of soot which takes place when the draught is sluggish. It is a very confusing practice, however, to speak of nominal horse-power in connection with boilers, since that is a quantity quite indeterminate, and the proper measure of a boiler's efficiency is its evaporative power.

EVAPORATIVE POWER OF BOILERS.

Q. The main thing, then, in boilers is their evaporative powers?

A. The proportions of tubular boilers, as of all boilers, should obviously have reference to the evaporation required, whereas the demand upon the boiler for steam is very often reckoned contingent upon the nominal horse-power of the engine; and as the nominal power of an engine is a conventional quantity by no means in uniform proportion to the actual quantity of steam consumed, perplexing complications as to the proper proportions of boilers have in consequence sprung up, to which most of the failures in that department of engineering may be imputed. It is highly expedient, therefore, in planning boilers for any particular engine to consider exclusively the actual power required to be produced, and to apportion the capabilities of the boiler accordingly.

Q. In other words, you would recommend the inquiry to be restricted to the mode of evaporating a given number of cubic feet of water in the hour, instead of embracing the problem how an engine of a given nominal power was to be supplied with steam?

A. I would first, as I have already stated, consider the actual power required to be produced, and then fix the amount of expansion to be adopted. If the engine had to work up to three times its nominal power, I should either increase correspondingly the quantity of evaporating surface in the boiler, or adopt such an amount of expansion as would increase threefold the efficacy of the steam, or combine in a modified manner both of these arrangements. Reckoning the evaporation of a cubic foot of water in the hour as equivalent to an actual horse-power in Watt's original engines, working with a low pressure and without expansion, and allowing a square yard or 9 square feet as the proper proportion of flue surface to evaporate a cubic foot of water in the hour, and which remains the proper proportion now as it was a hundred years ago, it is clear that I must either give 27 square feet of heating surface in the boiler to have a trebled power without expansion, or I must cut off the steam at one-seventh of the stroke to obtain a threefold power without increasing the quantity of heating surface. By cutting off the steam, however, at one-third of the stroke, a heating surface of 13½ square feet will give a threefold power, and it will usually be the most judicious course to carry the expansion as far as possible, and then to add the proportion of heating surface necessary to make good the deficiency still found to exist.

Q. But is it certain that a cubic foot of water evaporated in the hour is equivalent to an actual horse-power?

A. An actual horse-power as fixed by Watt is 33,000 lbs. raised one foot high in the minute; and in Watt's 40 horse-power engine with a 31½ inch cylinder, 7 feet stroke, and making 17½ strokes a minute, the effective pressure was 6·92 lbs. on the square inch, clear of all deductions. Now, as a horse-power is 33,000 lbs. raised one foot high, and as there are 6·92 lbs on the square inch, it is clear that 33,000 divided by 6·92, or 4,768 square inches with 6·92 lbs. on each, if lifted 1 foot or 12 inches high, will also be equal to a horse-power. But 4,768 square inches multiplied by 12 inches in height is 57,224·4 cubic inches, or 33·1 cubic feet, and this is the quantity of steam which must be expended per minute to produce an actual horse-power, supposing the steam to operate without expansion.

Q. But are 33 cubic feet of steam expended per minute equivalent to a cubic foot of water expended in the hour?

A. Not precisely, but nearly so. A cubic foot of water produces 1,669 cubic feet of steam of the atmospheric density of 15 lbs. per square inch, whereas a consumption of 33 cubic feet of steam in the minute is 1,980 cubic feet in the hour. In Watt's engines about one-tenth was reckoned as loss in filling the waste spaces at the top and bottom of the cylinder, making 1,872 cubic feet as the quantity consumed per hour without this waste; and in modern engines the waste at the ends of the cylinder is inconsiderable.

Q. What power was generated by a cubic foot of water in the case of the Albion Mill engines, when working without expansion?

A. In the Albion Mill engines, when working without expansion, it was found that 1 lb. of water in the shape of steam raised 28,489 lbs. 1 foot high. A cubic foot of water, therefore, or 62½ lbs., if consumed in the hour, would raise 1,780,562·5 lbs. one foot high in the hour, or would raise 29,676 lbs. one foot high in a minute; and if to this we add one-tenth for waste at the ends of the cylinder, a waste which hardly exists in modern engines, we have 32,643 lbs. raised one foot high in the minute, or a horse-power very nearly. In some cases the approximation appears still nearer. Thus, in a 40-horse engine working without expansion, Watt found that ·674 foot of water was evaporated from the boiler per minute which is just a cubic foot of water per horse-power per hour; but it is not certain in this case that the nominal and actual power were precisely identical. It will be quite safe, however, to reckon an actual horse-power as producible by the evaporation of a cubic foot of water in the hour in the case of engines working without expansion; and for boiling off this quantity in flue or waggon boilers, about 8 lbs. of coal will be required and 9 square feet of flue surface.

MARINE FLUE AND TUBULAR AND LOCOMOTIVE BOILERS.

Q. These proportions appear chiefly to refer to old boilers. I wish you to state what were the proportions of flue and tubular marine boilers, adopted after the tubular boiler had come in, about 1844.

A. In those more modern boilers the area of fire grate was less than in Mr. Watt's original boilers, where it was 1 square foot to 9 square feet of heating surface. The heat in the furnace was consequently more intense, and a somewhat less amount of surface sufficed to evaporate a cubic foot of water in the hour. In Boulton and Watt's more modern flue boilers they allowed for the evaporation of a cubic foot of water per hour 8 square feet of heating surface, 70 square inches of fire grate, 13 square inches sectional area of flue, 6 square inches sectional area of chimney, 14 square inches area over furnace bridges, ratio of area of flue to area of fire grate 1 to 5·4. To evaporate a cubic foot of water per hour in tubular boilers, the proportions were—heating surface 9 square feet, fire grate 70 square inches, sectional area of tubes 10 square inches, sectional area of back uptake 12 square inches, sectional area of front uptake 10 square inches, sectional area of chimney 7 square inches, ratio of diameter of tube to length of tube $\frac{1}{28}$th to $\frac{1}{30}$th, cubical content of boiler exclusive of steam chest 6·5 cubic feet, cubical content of steam chest 1·5 cubic feet.

Q. These proportions do not apply to locomotive boilers?

A. Not at all. In locomotive boilers the draught is maintained by the projection of the waste steam which escapes from the cylinders up the chimney, and the draught is much more powerful and the combustion much more rapid than in cases in which the combustion is maintained by the natural draught of a chimney—except, indeed, the chimney be of very unusual temperature and height. The proportions employed about the same time for locomotive boilers will be seen by the dimensions of a few locomotives of approved construction, which were found to give satisfactory results in practice, and which are recorded in the Table on the following page.

	Name of Engine			
	'G:eat Britain'	'Pallas'	'Snake'	'Sphinx'
Diameter of cylinder	18 in.	15 in.	14¼ in.	18 in.
Length of stroke .	24 in.	20 in.	21 in.	24 in.
Diameter of driving wheel . . .	8 ft.	6 ft.	6½ ft.	5 ft.
Inside length of fire-box . . .	53 in.	55 in.	41½ in.	44 in.
Inside width of fire-box . . .	63 in.	42 in.	43¼ in.	39½ in.
Height of fire-box above bars . .	63 in.	52 in.	48½ in.	55½ in.
Number of fire-bars .	29	—	32	16
Thickness of fire-bars	¾ in.	1¾ in.	⅝ in.	1 in.
Number of tubes .	305	134	181	142
Outside diameter of tubes . . .	2 in.	2 in.	1⅞ in.	2⅛ in.
Length of tubes .	11 ft. 3 in.	10 ft. 6 in.	10 ft. 3½ in.	14 ft. 3¼ in.
Space between tubes	½ in.	¾ in.	½ in.	—
Inside diameter of ferules . . .	$1\frac{3}{16}$ in.	1½ in.	$1\frac{5}{16}$ in.	1⅝ in.
Diameter of chimney	17 in.	15 in.	13 in.	15½ in.
Diameter of blast orifice . . .	5½ in.	4⅜ in.	4½ in.	4¾ in.
Area of fire grate .	21 sq. ft.	16·04 sq. ft.	12·4 sq. ft.	10·56 sq. ft.
Area of air space of grate . . .	11·4 sq. ft.	4·08 sq. ft.	5·54 sq. ft.	5 sq. ft.
Area of tubes . .	5·46 sq. ft.	2·40 sq. ft.	2·8 sq. ft.	2·92 sq. ft.
Area through ferules	4 sq. ft.	1·64 sq. ft.	2 sq. ft.	2·04 sq. ft.
Area of chimney .	1·77 sq. ft.	1·23 sq. ft.	·921 sq ft.	1·31 sq. ft.
Area of blast orifice .	23·76 sq. in.	16·8 sq. in.	14·18 sq. in.	17·7 sq. in.
Heating surface of tubes . . .	1627 sq. ft.	668·7 sq. ft.	823 sq. ft.	864·8 sq. ft.

Q. Are not other boilers sometimes now worked with a forced or artificial draught?

A. Yes; in the case of torpedo-boats and a few other war vessels, where the stoke-hole is made close and the air is forced into it by a fan. But it has long been known that a considerable economy of fuel and a considerable reduction in the size of the boiler may be obtained by this expedient, the use of which should, therefore, become universal. In America a close stoke-hole or close ash-pit, into which air is forced by a fan, was long ago introduced by Ericsson, and has been very widely adopted by commercial vessels in that country. But in this country the device has been employed to only a very limited extent altogether, and not at all yet in merchant vessels. The boilers of torpedo-boats, in consequence of the air being forced into a close stoke-hole, can be made very much on the proportions of a locomotive boiler. The tubes can be longer and smaller in diameter than in ordinary marine boilers, and the boilers, therefore, can be less in diameter, while from the high temperature of the furnace the heating surface is increased in efficiency, and the heat of the smoke can be more effectually extracted.

THE BLAST IN LOCOMOTIVES.

Q. What is the amount of draught produced in locomotive boilers in comparison with that existing in other boilers?

A. A good chimney of a land engine will produce a degree of exhaustion equal to from 1½ to 2½ inches of water. In locomotive boilers the exhaustion is in some cases equal to 12 or 13 inches of water, but from 3 to 6 inches is a more common proportion.

Q. And what force of blast is necessary to produce this exhaustion?

A. The amount varies in different engines, depending on the sectional area of the tubes and other circumstances. But, on the average, it may be asserted that such a pressure of blast as will support an inch of mercury, will maintain sufficient exhaustion in the smoke-box to support an inch of water; and this ratio holds whether the exhaustion is little or great. To produce an exhaustion in the smoke-box, therefore, of 6 inches of water, the waste steam would require to be of sufficient pressure to support a column of 6 inches of mercury, which is equivalent to a pressure of 3 lbs. on the square inch.

Q. How is the force of the blast regulated?

A. By the amount of contraction given to the mouth of the blast pipe, which is a pipe that conducts the waste steam from the cylinders and debouches at the foot of the chimney. If a strong blast be required, the mouth of this pipe requires to be correspondingly contracted; but such contraction throws a back pressure on the piston, and it is desirable to obtain the necessary draught with as little contraction of the blast pipe as possible. The blast pipe is sometimes a breeches pipe, of which the legs join just before reaching the chimney; but it is better to join the two cylinders below, and to let a single pipe ascend to within 12 or 18 inches of the foot of the chimney. If made with too short a piece of pipe above the joining, the steam will be projected against each side of the chimney alternately, and the draught will be damaged and the chimney worn. The blast pipe should not be regularly tapered, but should be large in the body and gathered in at the mouth.

Q. Is a large and high chimney conducive to strength of draught in locomotives?

A. It has not been found to be so. A chimney of three or four times its own diameter in height appears to answer fully as well as a longer one; and it was found that when in an engine with 17-inch cylinders a chimney of 15¼ inches was substituted for a chimney of 17½ inches, a superior performance was the result. The chimney of a locomotive should have half the area of the tubes at the ferrules, which is the most contracted part, and the blast orifice should have $\frac{1}{10}$th of the area of the chimney. The sectional area of the tubes through the ferrules should be as large as possible. Tubes without ferrules, it is found, pass one-fourth more air, and tubes with ferrules only at the fire-box end pass one-tenth more air, than when there are ferrules at both ends.

Q. Is the exhaustion produced by the blast as great in the fire-box as in the smoke-box?

A. Experiments have been made to determine this, and in few cases has it been found to be more than about half as great at ordinary speeds; but much depends on the amount of contraction in the tubes. In an experiment made with an engine having 147 tubes of 1¾ inches external diameter and 13 feet 10 inches long, and with a fire grate having an area of 9½ square feet, the exhaustion at all speeds was found to be three times greater in the smoke-box than in the fire-box. The exhaustion in the smoke-box was generally equivalent to 12 inches of water, while in the fire-box it was equivalent to only 4 inches of water; showing that 4 inches were required to draw the air through the grate and 8 inches through the tubes.

Q. What will be the increase of evaporation in a locomotive from a given increase of exhaustion?

A. The rate of evaporation in a locomotive or any other boiler will vary as the quantity of air passing through the fire, and the quantity of air passing through the fire will vary nearly as the square root of the exhaustion. With four times the exhaustion, therefore, there will be about twice the evaporation, and experiment shows that this theoretical law holds with tolerable accuracy in practice.

Q. But the same exhaustion will not be produced by a given strength of blast in all engines?

A. No ; engines with contracted fire grates and an inadequate sectional area of tubes will require a stronger blast than engines of better proportions ; but in any given engine the relations between the blast exhaustion and evaporation hold which have been already defined.

Q. Is the intensity of the draught under easy regulation ?

A. The intensity of the draught may easily be diminished by partially closing the damper, and it may be increased by contracting the orifice of the blast. A variable blast pipe, the orifice of which may be enlarged or contracted at pleasure, has been used in some cases. There are various devices for this purpose, but the best appears to be that adopted in Stephenson's engine, where a conical nozzle was moved up or down within the blast pipe, which was made somewhat larger in diameter than the base of the cone, but with a ring projecting internally, against which the base of the cone abutted when the nozzle was pushed up. When the nozzle stood at the top of the pipe, the whole of the steam had to pass through it, and the intensity of the blast was increased by the increased velocity thus given to the steam ; whereas, when the nozzle was moved downward, the steam escaped through the annular opening left between the nozzle and the pipe, as well as through the nozzle itself, and the intensity of the blast was diminished by the enlargement of the opening for the escape of the steam thus made available. This plan, however, is now little used.

Q. What is the best diameter for the tubes of locomotive boilers ?

A. Taking for types of differing systems examples of well-known locomotives, made before the best proportions were finally settled, it will be found that Bury's locomotive with 14-inch cylinders contained 92 tubes of 2⅛th inches external diameter, and 10 feet 6 inches long; whereas Stephenson's locomotive with 15-inch cylinders contained 150 tubes of 1⅝ths external diameter, 13 feet 6 inches long. In Stephenson's boiler, in order that the part of the tubes next the chimney might be of any avail for the generation of steam, the draught had to be very intense, which in its turn involved a considerable expenditure of power ; and it is questionable whether the increased expenditure of power upon the blast, in Stephenson's long-tubed locomotives, was compensated by the increased generation of steam consequent upon the extension of the heating surface. When the tubes are small in diameter they are apt to become partially choked with pieces of coke ; but an internal diameter of 1⅝ths may be employed without inconvenience, if the draught be of medium intensity and the tubes not very long.

Q. Will you illustrate the relation between the length and diameter of locomotive tubes by a comparison with the proportion of flues in flue boilers?

A. In most locomotives the velocity of the draught is such that it would require very long tubes to extract the heat from the products of combustion, if the heat were transmitted through the metal of the tubes with only the same facility as through the iron of ordinary flue boilers. The 'Nile' steamer, with engines of 110 nominal horse-power each, and with two boilers having two independent flues in each, of such dimensions as to make each flue equivalent to 55 nominal horse-power, worked at 62 per cent. above the nominal power, so that the actual evaporative efficacy of each flue would be equivalent to 89 actual horse-power, supposing the engines to operate without expansion; but as the mean pressure in the cylinder was somewhat less than the initial pressure, the evaporative efficacy of each flue might be reckoned equivalent to 80 actual horse-power. With this evaporative power there was a calorimeter of 990 square inches, or 12·3 square inches per actual horse power; whereas in Stephenson's locomotive with 150 tubes, if the evaporative power were taken at 200 cubic feet of water in the hour, the engine would be equal to 200 actual horse-power. If the internal diameter of the tubes be taken at 1⅝ths or thirteen-eighths of an inch, the calorimeter per actual horse-power will only be 1·1136 square inches, or in other words the calorimeter in the locomotive boiler will be 11·11 times less than in the flue boiler for the same power, so that the draught in the locomotive must be 11·11 times stronger, and the ratio of the length of the tube to its diameter 11·11 times greater than in the flue boiler, supposing the heat to be transmitted with only the same facility. The flue of the 'Nile' would require to be 35½ inches in diameter if made of the cylindrical form, and 47¾ feet long: the tubes of a locomotive of 1⅜ths inch diameter would only require to be 22·19 inches long with the same velocity of draught; but as the draught is 11·11 times faster than in a flue boiler, the tubes ought to be 246·558 inches, or about 20½ feet long, according to this proportion. In practice, however, they are one-third less than this, which reduces the heating surface from 9 to 6 square feet per actual horse-power, and this length even is found to be inconvenient. It is greatly preferable, therefore, to increase the calorimeter, and diminish the intensity of the draught.

BOILER CHIMNEYS.

Q. By what process do you ascertain the dimensions of the chimney of a land boiler?

A. By a reference to the volume of air it is necessary in a given time to supply to the burning fuel, and to the velocity of motion produced by the rarefaction in the chimney; for the area of the chimney requires to be such, that with the velocity due to that rarefaction, the quantity of air requisite for the combustion of the fuel shall pass through the furnace in the specified time. Thus, if 200 cubic feet of air of the atmospheric density are required for the combustion of a pound of coal—though 250 feet is nearer the quantity generally required—and 10 lbs. of coal per horse-power per hour are consumed by an engine, then 2,000 cubic feet of air must be supplied to the furnace per horse-power per hour, and the area of the chimney must be such as to deliver this quantity at the increased bulk due to the high temperature of the chimney, when moving with the velocity the rarefaction within the chimney occasions, and which, in small chimneys, is usually such as to support a column of half an inch of water. The velocity with which a denser fluid flows into a rarer one is equal to the velocity a heavy body acquires in falling through a height equal to the difference of altitude of two columns of the heavier fluid of such heights as will produce the respective pressures; and, therefore, when the difference of pressure or amount of rarefaction in the chimney is known, it is easy to tell the velocity of motion which ought to be produced by it. In practice, however, these theoretical results are not to be trusted, until they have received such modifications as will make them representative of the practice of the most experienced constructors.

Q. What, then, is the rule followed by the most experienced constructors?

A. Boulton and Watt's rule for the dimensions of the chimney of a land engine is as follows:—Multiply the number of pounds of coal consumed under the boiler per hour by 12, and divide the product by the square root of the height of the chimney in feet; the quotient is the area of the chimney in square inches in the smallest part. A factory chimney suitable for a 20-horse boiler is commonly made about 20 inches square inside, and 80 feet high; and these dimensions are those which answer to a consumption of 15 lbs. of coal per horse-power per hour, which is a very common consumption in factory engines of the old type. If 15 lbs. of coal be consumed per horse-power per hour, the total consumption per hour in a 20-horse boiler will be 300 lbs., and 300 multiplied by 12 = 3,600, and divided by 9 (the square root of the height) = 400, which is the area of the chimney in square inches. It will not answer well to increase the height of a chimney of this area to more than 40 or 50 yards, without also increasing the area, nor will it be of utility to increase the area much without also increasing the height. The quantity of coal consumed per hour in pounds, multiplied by 5, and divided by the square root of the height of the chimney, is the proper collective area of the openings between the bars of the grate for the admission of air to the fire.

Q. Is this rate applicable to the chimneys of steam vessels?

A. In steam vessels Boulton and Watt were long in the habit of allowing 8½ square inches of area of chimney per horse-power, but they subsequently allowed 6 square inches to 7 square inches. In some steam vessels a steam blast like that of a locomotive, but of a smaller volume, is used in the chimney, and many of the evils of a boiler deficient in draught may be remedied by this expedient. But a steam blast in a low-pressure engine occasions an obvious waste of steam; it also makes an unpleasant noise, and in steam vessels it frequently produces the inconvenience of carrying the smaller pieces of the coal up the chimney, and scattering them over the deck among the passengers. It is advisable, therefore, to give a sufficient calorimeter in all low-pressure boilers, and a sufficient height of chimney to enable the chimney to operate without a steam jet; but it is useful to know that a steam jet is a resource in the case of a defective boiler, bad coals, or where the boiler has to be urged beyond its power.

STEAM ROOM AND PRIMING.

Q. What is the capacity of steam room allowed in boilers per horse-power?

A. The capacity of steam room allowed by Boulton and Watt in their land waggon boilers was 8¾ cubic feet per horse-power in the 2 horse-power boiler, and 5¾ cubic feet in the 20 horse-power boiler; and in the larger class of boilers, such as those suitable for 30 and 45 horse-power engines, the capacity of the steam room did not fall below this amount, and indeed was nearer 6 than 5¾ cubic feet per horse-power. The content of water was 18½ cubic feet per horse-power in the 2 horse-power boiler, and 15 cubic feet per horse-power in the 20 horse-power boiler.

Q. Was this the proportion Boulton and Watt allowed in their marine boilers?

A. Boulton and Watt in their early steam vessels were in the habit of allowing for the capacity of the steam space in marine boilers 16 times the content of the cylinder; but as there were two cylinders, this was equivalent to 8 times the content of both cylinders, which was the proportion commonly followed in their land engines, and which agrees very nearly with the proportion of between 5 and 6 cubic feet of steam room per horse-power already referred to. Taking for example an engine with 23 inches diameter of cylinder and 4 feet stroke, which will be 18·4 horse-power, the area of the cylinder will be 415·476 square inches, which multiplied by 48, the number of inches in the stroke, will give 19,942·848 for the capacity of the cylinder in cubic inches; 8 times this is 159,542·784 cubic inches, or 92·3 cubic feet; 92·3 divided by 18·4 is rather more than 5 cubic feet per horse-power.

Q. Is the production of the steam in the boiler uniform throughout the stroke of the engine?

A. It varies with the slight variations in the pressure within the boiler throughout the stroke. Usually the larger part of the steam is produced during the first part of the stroke of the engine, for there is then the largest demand for steam, as the steam being commonly cut off somewhat before the end of the stroke, the pressure rises somewhat in the boiler during that period, and little steam is then produced. There is less necessity that the steam space should be large when the flow of steam from the boiler is very uniform, as it will be where there are two engines attached to the boiler at right angles with one another, or where the engines work at a great speed, as in the case of locomotive engines. A high steam chest, too, by rendering boiling over into the steam pipes, or priming, as it is called, more difficult, obviates the necessity for so large a steam space; as does also a perforated steam pipe stretching through the length of the boiler, so as not to take the steam from one place. The use of steam of a high pressure, worked expansively, has the same operation; so that in modern marine boilers, of the tubular construction, where the whole or most of these modifying circumstances exist, there is no necessity for so large a proportion of steam room as 5 or 6 cubic feet per nominal horse-power, and about one half a cubic foot of steam room per cubic foot of water evaporated, more nearly represents the general practice.

Q. Is this the proportion of steam room adopted in locomotive boilers?

A. No; in locomotive boilers the proportion of steam room per cubic foot of water evaporated is considerably less even than this. It does not usually exceed $\frac{1}{5}$ of a cubic foot per cubic foot of water evaporated; and with clean water, with a steam dome a few feet high set on the barrel of the boiler, or with a perforated pipe stretching from end to end of the barrel, and with the steam room divided about equally between the barrel and the fire-box, very little priming is found to occur even with this small proportion of total steam room. About $\frac{3}{4}$ the depth of the barrel is usually filled with water, and $\frac{1}{4}$ with steam.

Q. What is priming?

A. Priming is a violent agitation of the water within the boiler, in consequence of which a large quantity of water passes off with the steam in the shape of froth or spray. Such a result is injurious, both as regards the efficacy of the engine and the safety of the engine and boiler; for the large volume of hot water carried over by the steam in condensing engines impairs the vacuum, and throws a great load upon the air pump, which diminishes the speed and available power of the engine; and the existence of water within the cylinder, unless there be safety valves upon the cylinder to permit its escape, will very probably cause some part of the machinery to break, by suddenly arresting the motion of the piston when it meets the surface of the water,—the slide valve being closed to the condenser before the termination of the stroke in all engines with lap upon the valves, so that the water within the cylinder is prevented from escaping in that direction if the slide valve be of the kind which will not leave its face. At the same time the boiler is emptied of its water too rapidly for the feed pump to be able to maintain the supply, and the tubes are in danger of being burnt from a deficiency of water above them.

Q. What are the causes of priming?

A. The causes of priming are an insufficient amount of steam room, an inadequate area of water-level, an insufficient width between the flues or tubes for the ascent of the steam and the descent of water to supply the vacuity the rise of the steam occasions, and the use of dirty water. New boilers prime more than old boilers, and steamers entering rivers from the sea are more addicted to priming than if sea or river water alone had been used in the boilers—probably from the boiling point of salt water being higher than that of fresh, whereby the salt water acts like so much molten metal in raising the fresh water into steam. Opening the safety valve suddenly may make a boiler prime, and if the safety valve be situated near the mouth of the steam pipe, the spray or foam thus created may be mingled with the steam passing into the engine, and materially diminish its effective power; but if the safety valve be situated at a distance from the mouth of the steam pipe, the quantity of foam or spray passing into the engine may be diminished by opening the safety valve; and in locomotives, therefore, it is found beneficial to have a safety valve on the barrel of the boiler at a point remote from the steam chest, by partially opening which, any priming in that part of the boiler adjacent to the steam chest is checked, and a purer steam than before passes to the engine.

Q. What is the proper remedy for priming?

A. When a boiler primes, the engineer generally closes the throttle valve, partially turns off the injection water, if a condensing engine operating by jet, and opens the furnace doors, whereby the generation of steam is checked, and a less violent ebullition in the boiler suffices. Where the priming arises from an insufficient amount of steam room, it may be mitigated by putting a higher pressure upon the boiler and working more expansively, or by the interposition of a perforated plate between the boiler and the steam chest, which breaks the ascending water and liberates the steam. In some cases, however, it may be necessary to set a second steam chest on the top of the existing one, and it will be preferable to establish a communication with this new chamber by means of a number of small holes, bored through the iron plate of the boiler, rather than by a single large orifice. Where priming arises from the existence of dirty water in the boiler, the evil may be remedied by the use of collecting vessels, or by blowing off largely from the surface; and where it arises from an insufficient area of water-level, or an insufficient width between the flues for the free ascent of the steam and the descent of the superincumbent water, the evil may be abated by the addition of circulating pipes in some part of the boiler, which will allow the water to descend freely to the place from whence the steam rises, the width of the water spaces being virtually increased by restricting their function to the transmission of a current of steam and water to the surface. It is desirable to arrange the heating surface in such a way that the feed water entering the boiler at its lowest point is heated gradually as it ascends, until towards the superior part of the boiler it is raised gradually into steam ; but in all cases there will be currents in the boiler for which it is proper to provide. The steam pipe proceeding to the engine should obviously be attached to the highest point of the steam chest, in boilers of every construction.

Q. Having now stated the proportions proper to be adopted for evaporating any given quantity of water in steam boilers, will you proceed to show how you would proportion a boiler to do a given amount of work—say a locomotive boiler which will propel a train of 100 tons weight at a speed of 50 miles an hour?

A. According to experiments on the resistance of railway trains at various rates of speed made by Sir D. Gooch, of the Great Western Railway, it appears that a train weighing with locomotive, tender, and carriages, about 100 tons, experiences, at a speed of 50 miles an hour, a resistance of about 3,000 lbs., or about 30 lbs. per ton ; which resistance includes the resistance of the engine as well as that of the train. This, therefore, is the force which must be imparted at the circumference of the driving wheels, except that small part intercepted by the engine itself, and the force exerted by the pistons must be greater than that at the circumference of the driving wheel, in the proportion of their slower motion, or in the proportion of the circumference of the driving wheel, to the length of a double stroke of the engine. If the diameter of the driving wheel be 5½ feet, its circumference will be 17·278 feet, and if the length of the stroke be 18 inches, the length of a double stroke will be 3 feet. The pressure on the pistons must therefore be greater than the traction at the circumference of the driving wheel, in the proportion of 17·278 to 3, or, in other words, the mean pressure on the pistons must be 17,278 lbs. ; and the area of cylinders, and pressure of steam, must be such as to produce conjointly this total pressure. It thus becomes easy to tell the volume and pressure of steam required, which steam in its turn represents its equivalent of water which is to be evaporated from the boiler, and the boiler must be so proportioned, by the rules already given, as to evaporate this water freely. In the case of a steam vessel the mode of procedure is the same, and when the resistance and speed are known, it is easy to tell the equivalent value of steam.

STRENGTH OF BOILERS.

Q. What strain should the iron of boilers be subjected to in working?

A. The iron of boilers, like the iron of machines or structures, is capable of withstanding a tensile strain of from 50,000 to 60,000 lbs. upon every square inch of section; but it will only bear a third of this strain without permanent derangement of structure, and it does not appear expedient in any boiler to let the strain much exceed 5,000 lbs. upon the square inch of sectional area of metal, especially if it is liable to be weakened by corrosion.

Q. Have any experiments been made to determine the strength of boilers?

A. The question of the strength of boilers was investigated very elaborately some years ago by a committee of the Franklin Institute, in America, and it was found that the tenacity of iron boiler plate increased with the temperature up to 550°, at which point the tenacity began to diminish. At 32°, the cohesive force of a square inch of section was 56,000 lbs.; at 570°, it was 66,500 lbs.; at 720°, 55,000 lbs.; at 1,050°, 32,000 lbs.; at 1,240°, 22,000 lbs.; and at 1,317°, 9,000 lbs. Copper follows a different law, and appears to be diminished in strength by every addition to the temperature. At 32° the cohesion of copper was found to be 32,800 lbs. per square inch of section, which exceeds the cohesive force at any higher temperature, and the square of the diminution of strength seems to keep pace with the cube of the increased temperature. Strips of iron cut in the direction of the fibre were found to be about 6 per cent. stronger than when cut across the grain. Repeated piling and welding was found to increase the tenacity of the iron, but the result of welding together different kinds of iron was not found to be favourable. The accidental overheating of a boiler was found to reduce the ultimate or maximum strength of the plates from 65,000 lbs. to 45,000 lbs. per square inch of section, and riveting the plates was found to occasion a diminution in their strength to the extent of one-third. These results, however, are not precisely the same as those obtained by Sir W. Fairbairn.

Q. What were the results obtained by him?

A. He found that boiler plate bore a tensile strain of 23 tons per square inch before rupture, which was reduced to 35,700 lbs. per square inch when joined together by a double row of rivets, and

28,600 lbs. when joined together by a single row of rivets, owing to the weakening effect of the rivet holes.

Q. What pressure do cylindrical boilers sustain in practice?

A. In some of the early locomotive boilers, which were worked with a pressure of 80 lbs. upon the square inch, the thickness of the plates was $\frac{5}{16}$ths of an inch, while the barrel of the boiler was 39 inches in diameter. It will require a length of 3·2 inches of the boiler when the plates are $\frac{5}{16}$ths thick to make up a sectional area of one square inch, and the separating force will be 39 times 3·2 multiplied by 80, which makes the separating force 9,984 lbs., sustained by two square inches of sectional area—one on each side; or the strain is 4,992 lbs. per square inch of sectional area. The accession of strength derived from the boiler ends is not here taken into account in this calculation, but neither is the weakening effect counted that is caused by the rivet-holes. Some other locomotives of 4 feet diameter of barrel and of $\frac{3}{8}$ths iron were worked to as high a pressure as 200 lbs. Such a load upon the iron is certainly unsafe, though an approach to it has now become common in both locomotive and marine boilers. Thus, in various examples of modern locomotives the pressure is $12\frac{3}{4}$ atmospheres or 191 lbs. per square inch with a diameter of barrel of 4 feet or 48 inches, and a thickness of iron of ·47 or about $\frac{15}{32}$nds of an inch. The separating pressure is $191 \times 48 = 9{,}180$ lbs., which is supported by a hoop of iron 48 inches diameter, 1 inch broad, and $\frac{15}{32}$ thick. If we increase the thickness of the hoop by $\frac{1}{32}$nd, so as to make it half an inch thick, we shall increase the resistance to bursting by $\frac{1}{32}$nd on each side, or a $\frac{1}{16}$th on the two sides taken together; and if we increase the strength by $\frac{1}{16}$th, we must also suppose the pressure to be increased $\frac{1}{16}$th, in order to get the strain upon each square inch of section as really existing. Now 9,180 lbs. increased by $\frac{1}{16}$th $= 9{,}753$ lbs. This is the separating pressure in such boilers per square inch of section of iron, or in round numbers we may call it 10,000 lbs.

Q. Upon what principle should the strength of steam boilers be determined?

A. Upon the same principle which governs the strength of other engineering structures, and which directs that while in the case of constant loads a strength of three times the breaking weight is sufficient, yet in the case of variable or moving loads a strength of six times the breaking weight is indispensable to safety.

Q. You have stated that the maximum strength or breaking weight of boiler plate varies according to quality from 50,000 to 60,000 lbs. per square inch of section?

A. Yes.

Q. You have also stated that the weakening effect of the rivet-holes in the case of double-riveting is to reduce the strength reckoned on the whole plate to 35,700 lbs. per square inch of section?

A. That is so.

Q. Then if it be permissible to take only one-sixth of the ultimate strength as the working strength, does it not follow that one-sixth of 35,700, or a little under 6,000 lbs., is the maximum strain to which the iron of boilers should be subjected per square inch of section?

A. That, no doubt, is so, if the riveted seams be supposed to run in a continuous line from end to end of the boiler. But the plates are usually introduced so as to break joint as in masonry—the end of one plate coming opposite to the middle of that next it. This is believed to increase the strength about one-sixth, which would raise the maximum safe working strength to 7,000 lbs. per square inch of section of iron. Any strain beyond this is on general grounds to be reprehended.

Q. What was the safe working strain for boilers assumed in former editions of this work?

A. 5,000 lbs. per square inch of section of iron. But the quality of iron boiler plate has improved of late years, and boilers are now frequently formed of steel plate, which is a good deal stronger than iron. Formerly, too, boilers were much more liable to weakening from internal corrosion than now, especially in the region of the steam chest, from the superheating action of the chimney in passing through it; whereas the smoke is not now conducted through the steam chest at all, but so soon as it emerges from the tubes it enters the chimney. Formerly it was necessary not merely to allow sufficient material for strength, but also to leave a larger margin for wear than is now required from the diminished internal oxidation. In modern marine boilers such oxidation as occurs is below the water. Formerly it was almost wholly above the water line, and was very serious in amount.

Q. What is the strength of cast iron cylinders or pipes, as compared with double-riveted cylinders or pipes of wrought iron of the same thickness?

A. It is about half as great.

Q. Is the strength of riveted work much affected by the accurate pitching of the rivet-holes?

A. That has a considerable influence, and in boilers of considerable thickness, whether of iron or steel, the holes are now very frequently drilled. In steel plates it is found that the condensation of the metal round the rivet-hole, produced by the punching action, has an injurious straining effect, and the plates are therefore either annealed after punching or the holes are rymered out, so as to remove the compressed annulus.

Q. Can you give a safe rule for determining the proper thickness of the shell of a double-riveted iron boiler?

A. The working pressure, as we have seen, should not be more than one-sixth of the bursting pressure, and the strength of the iron per square inch of section is reduced to 42,000 in consequence of the weakening effect of the rivet-holes. To get the proper thickness, multiply six times the working pressure by the radius of the cylindrical shell, and divide the product by 42,000. The quotient will be the proper thickness of the iron of the shell in inches.

Q. Will you illustrate this rule by finding the proper thickness to be given to the double-riveted shell of an iron boiler 4 feet diameter, with a working pressure of steam of 150 lbs. per square inch?

A. Six times 150 lbs. = 900 lbs., which is the bursting pressure per square inch if the boiler be properly proportioned. The radius of the shell will be 24 inches, and $900 \times 24 \div 42{,}000 = {\cdot}514$, which is the proper thickness of the iron of the shell in inches.

Q. If you have the thickness of the iron, and want to know the proper working pressure for that thickness, how do you proceed?

A. Multiply 42,000 by the thickness in inches, and divide by the radius of the shell in inches. This will give the bursting pressure per square inch, one-sixth of which is the proper working pressure per square inch.

Q. If you have both the thickness of the iron for the shell and the intended pressure at which the boiler is to work, and wish to know what diameter of boiler you may employ with such thickness and pressure, how is this to be determined?

A. Multiply the thickness of the iron in inches by 42,000, and divide the product by six times the working pressure in lbs. per square inch. The quotient is the radius or semi-diameter of the shell. Thus, if the thickness of the iron be ·514 inches and the working pressure 150 lbs. per square inch, then ·514 × 42,000 ÷ 900, which is six times the working pressure = 24, which is the radius of the shell in inches, and its diameter is of course twice this, or 48 inches.

Q. What is the proportion usually observed between the diameter of rivets in boilers and the thickness of the plates they hold together?

A. A punched rivet-hole cannot be of less diameter than the thickness of the plate, else the punch will not pierce the iron but will be crumpled up. A good rule for the diameter of rivet is 1·2 times the square root of the thickness of the plate. In overlapped joints subjected to considerable pressure the tendency is to draw the overlap straight, which causes the plates to be grooved internally. It is better, therefore, to allow the ends of the plates to butt, and to apply covering plates either on both sides of the shell or on the inside alone. But these plates, if only applied internally, should be of greater thickness than the plate to which they are applied, or, if applied both within and without, they should be of greater collective thickness. The more material proportions proper for the riveted joints of boilers are given in the following table:—

Thickness of plate	Diameter of rivet	Length of rivet from head	Pitch of rivets, centre to centre	Breadth of lap, single riveting
3/16	3/8	7/8	1 1/4	1 1/4
1/4	1/2	1 1/4	1 1/2	1 1/2
5/16	5/8	1 3/8	1 5/8	1 5/8
3/8	3/4	1 5/8	1 3/4	2
1/2	13/16	2 1/4	2	2 1/4
5/8	15/16	2 3/4	2 1/2	2 3/4
3/4	1 1/16	3 1/4	3	3 1/4

In the case of double-riveted joints two-thirds more breadth of lap is allowed.

Q. What is the best species of boiler known at the present time for strength and lightness combined?

A. A steel boiler double-riveted with rivet-holes not punched but drilled. Machine riveting, too, is much more efficient than hand riveting, and with it less caulking suffices. The riveting cylinder should be surrounded by an annular cylinder, the function of which is to press the plates close together before the rivet is inserted, to the end that a fin may not be forced out between the plates. A steel boiler with drilled rivet-holes will be stronger than an iron boiler of the same scantling in the proportion of 10 to 7, and such boilers will bear with enduring safety a strain of 10,000 lbs. per square inch on the section of the metal. But the comparative exemption from explosions which this country has hitherto enjoyed, in the case of boilers of the most important class, should not be jeopardised by any attempt to diminish the weight at the expense of the safety.

Q. In boilers which are not of a cylindrical form, how do you procure the requisite strength?

A. Where the sides of the boiler are flat, instead of being cylindrical, a sufficient number of stays must be introduced to withstand the pressure; and it is expedient not to let the strain upon these stays, where liable to corrosion, be more than 3,000 lbs. per square inch of section. The stays should be small and numerous rather than large and few in number, as, when large stays are employed, it is difficult to keep them tight at the ends, and oxidation of the shell follows from leakage at the ends of the stays. All boilers should be proved, when new, to twice the pressure they are intended to bear in working, and they should be proved occasionally by the hand pump when in use, to detect any weakness which corrosion may have occasioned.

Q. Are cylindrical boilers sometimes fitted with cylindrical internal furnaces?

A. Yes.

Q. Are these furnaces as strong as the shell if made of iron of the same thickness?

A. They are about as strong if half the diameter of the shell. But such furnaces are now generally made of corrugated iron, whereby thinner plates may be employed than would otherwise be required.

BOILER EXPLOSIONS.

Q. What is the chief cause of boiler explosions?

A. The chief cause of boiler explosions is, undoubtedly, too great a pressure of steam, or an insufficient strength of boiler, generally resulting from oxidation; but many explosions have also arisen from the flues having been suffered to become red hot. If the safety valve of a boiler be accidentally jammed, or if the plates or stays be much worn by corrosion, while a high pressure of steam is nevertheless maintained, the boiler necessarily bursts; and if, from an insufficiency of water in the boiler, or from any other cause, the flues become highly heated, they may be forced down by the pressure of the steam, and a partial explosion may be the result. The worst explosion is where the shell of the boiler bursts; but the collapse of a furnace or flue is also very disastrous, generally to the persons in the engine room; and sometimes the shell bursts and the flues collapse at the same time; for if the flues get red hot, and water be thrown upon them either by the feed pump or otherwise, the generation of steam may be too rapid for the safety valve to permit its escape with sufficient facility, and the shell of the boiler may, in consequence, be rent asunder. Sometimes the iron of the flues becomes highly heated in consequence of the improper configuration of the parts, which, by retaining the steam in contact with the metal, prevents the access of the water. The bottoms of large flues, upon which the flame beats down, are very liable to injury from this cause; and the iron of flues thus acted upon may be so softened that the flues will collapse upwards with the pressure of the steam. The flues of boilers using salt water may also become red hot in some parts from the attachment of scale, which, from its imperfect conducting power, will cause the iron to be unduly heated; and if the scale be accidentally detached, a partial explosion may occur in consequence.

Q. Does the contact of water with heated metal occasion an instantaneous generation of steam?

A. It is found that a sudden disengagement of steam does not immediately follow the contact of water with the hot metal, for water thrown upon red hot iron is not immediately converted into steam, but assumes the spheroidal form and rolls about in globules over the surface. These globules, however high the temperature of the metal may be on which they are placed, never rise above the temperature of 205°, and give off but very little steam; but if the temperature of the metal be lowered, the water ceases to retain the spheroidal form, and comes into intimate contact with the metal, whereby a rapid disengagement of steam takes place. If water be poured into a very hot copper flask, the flask may be corked up, as there will be scarce any steam produced so long as the high temperature is maintained; but so soon as the temperature is suffered to fall below 350° or 400°, the spheroidal condition being no longer maintainable, steam is generated with rapidity, and the cork will be projected from the mouth of the flask with great force.

Q. What precautions can be taken to prevent boiler explosions?

A. One useful precaution against the explosion of boilers from too great an internal pressure, consists in the application of a steam gauge to each boiler, which will make the existence of any undue pressure in any of the boilers immediately visible; and every boiler should have a safety valve of its own, the passage leading to which should have no connection with the passage leading to any of the stop valves used to cut off the connection between the boilers, so that the action of the safety valve may be made independent of the action of the stop valve. In some cases stop valves have jammed, or have been carried from their seats into the mouth of the pipe communicating between them, or have not been opened, and the action of the safety valves should be rendered independent of all such accidents. Safety valves, themselves, sometimes stick fast from corrosion, from the spindles becoming bent, from a distortion of the boiler top with a high pressure, in consequence of which the spindles become jammed in the guides, from a larger expansion of the brass seat than of the cast iron socket in which it is set, and from various other causes which it would be tedious to enumerate.

Q. What was the cause of the explosion in H.M. steamer 'Thunderer'?

A. The stop valves of the boilers were valves closed by a screw against the pressure of the steam. There were four boilers in the vessel, each fitted with its safety valve and stop valve. The stop valve of the boiler which burst had been accidentally omitted to be opened, and the safety valve, though acting all right when cold, stuck when hot from the spindle having been made too close a fit in the hole it passed through. There was consequently no outlet afforded for the steam, and the pressure necessarily accumulated until it burst the boiler.

CHAPTER IV.

PROPORTIONS OF ENGINES.

SAFETY VALVES.

Q. What size of orifice is commonly allowed for the escape of the steam through the safety valve in low-pressure engines?

A. About 0·8 of a circular inch per horse-power, or a circular inch per 1¼ horse-power, was formerly a common proportion. The following rule, however, will give the dimensions suitable for all kinds of engines, whether high or low pressure:—Multiply the square of the diameter of the cylinder in inches by the speed of the piston in feet per minute, and divide the product by 375 times the pressure on the boiler per square inch; the quotient is the proper area of the safety valve in square inches. This rule, of course, supposes that the evaporating surface has been properly proportioned to the engine power.

Q. What will be the proper diameter of safety valve, according to this rule, in the case of a high-pressure engine with cylinder 9·2 inches diameter, and 18·4 inches stroke, making 210 strokes per minute with 120 lbs. steam?

A. The square of the diameter of the cylinder in inches will be 84·64. The speed of the piston will be 644·7 feet per minute, and 84·64 × 644·7 = 54,567. Then 375 times the pressure in the boiler per square inch = 45,000, and 54,567 ÷ 45,000 = 1·2 square inches area, or 1¼ inches diameter for the safety valve.

Q. In several foreign countries is not the size of the safety valve prescribed by law?

A. It is.

Q. Can you give the rule employed in France for determining the diameter?

A. In France the diameter of the safety valve in centimetres is

2·6 times the square root of the heating surface in square metres divided by the number of atmospheres of pressure, less 0·12.

Q. Will you illustrate this rule by applying it to the example you have just taken to illustrate the other rule?

A. A metre being 3·28 feet, a square metre will be 10·76 square feet, and 585 square feet of heating surface will be 54·35 square metres, the square root of which is 7·37. The pressure being 120 lbs. per square inch, is equivalent to 8 atmospheres, which, diminished by 0·12, is 7·88, and 7·37 divided by 7·88 = ·93. This, multiplied by 2·6 = 2·418 centimetres, or ·95 English inches, which is the diameter of the valve. A centimetre is 0·3,937 English inches.

Q. Are the same proportions adopted in other Continental countries?

A. In Holland and some other countries a similar, but not identical, rule is adopted.

Q. What is this other rule?

A. The diameter of the valve in centimetres is made 2·6 times the square root of the heating surface in square metres, divided by the pressure in kilogrammes per square centimetre, increased by the constant 0·612.

Q. Will you go through the figures as in the previous example?

A. The pressure, being 120 lbs. per square inch, will be 54·5 kilogrammes per square inch, there being 2·2 lbs. in a kilogramme. A square centimetre is ·155 of a square inch, and 54·5 × ·155 = 8.4475, or say 8·45, which is the pressure in kilogrammes per square centimetre. This increased by the constant 0·612 = 9·062. The heating surface being 54·35 square metres, the square root of this is 7·37, so we have 7·37 ÷ by 9·062 = ·814, and this multiplied by 2·6 = 2·1,164 centimetres, or ·833 English inches, which is the diameter of the valve. Both of these foreign rules therefore give a diameter somewhat less than that obtained by the English rule.

Q. Is this English rule applicable to locomotives?

A. It is applicable to high-pressure engines of every kind. The dimensions of safety valves, however, in practice are very variable, being in some cases greater, and in some cases less, than what the rule gives, the consideration being apparently as often what proportions will best prevent the valve from sticking in its seat, as what proportions will enable the steam to escape freely. In Bury's locomotives, the safety valve was generally 2½ inches diameter for all sizes of boiler, and the valve was kept down by a lever, formed in the proportion of 5 to 1, fitted at one end with a *Salter's* balance. As the area of the valve was 5 square inches, the number of pounds shown on the spring balance denoted the number of pounds pressure on each square inch of the boiler.

Q. Is there only one safety valve in a locomotive boiler?

A. There are always two.

Q. And are they always pressed down by a spring balance and never by weights?

A. They are never pressed down by weights; in fact, weights would not answer on a locomotive at all, as they would jump up and down with the jerks or jolts of the train, and cause much of the steam to escape. In land and marine boilers, however, the safety valve is often kept down by weights; but when weights are used in steam vessels, a good deal of steam is lost in stormy weather by the opening of the valve, owing to the inertia of the weights when the ship sinks suddenly in the deep recess between the waves. Springs, therefore, are now widely adopted in steam vessels also.[1]

Q. What other sizes of safety valves have been used in locomotives?

A. Some were as large as 4 inches diameter, giving 12 square inches of area; and others as small as $1\frac{3}{16}$ inch diameter, giving 1 square inch of area.

Q. And were these valves all pressed down by a Salter's spring balance?

A. In the great majority of cases they were so, and the lever by which they were pressed down was generally graduated in the proportion of the area of the valve to unity; that is, in the case of a valve of 12 inches area, the long end of the lever to which the spring balance was attached was 12 times the length of the short end, so that the weight or pressure on the balance showed the pressure per square inch on the boiler. In some cases, however, a spiral spring, and in other cases a pile of elliptical springs, was placed directly upon the top of the valve. It was difficult, when the lever was divided in such a proportion as 12 to 1, to get sufficient lift of the valve without a large increase of pressure on the spring; and it is expedient in all cases to employ a shorter lever, which involves either a reduction in the area of the valve, or an increased strength in the spring.

Q. Are there any stipulations prescribed by foreign Governments to ensure the safety of boilers besides those which relate to the proportions of safety valves?

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[1] Spring safety valves in steam vessels were first introduced by me into the 'Don Juan' steamer, in 1837.

A. There are several others. The boiler has to be tried under steam at double the sanctioned working pressure. The long end of the safety valve lever must not be more than 5 times the length of the short end; the manhole must be strengthened round its edge by a plate iron ring riveted to the boiler, so as to double the thickness at that part, and a brass band outside the boiler must mark the proper position of the water level. There must be a blow-off cock to empty the boiler, or to enable a portion of the water to be blown out when desired, and in many cases it is provided that there shall be a back-pressure valve somewhere in the feed pipe near the boiler, and that a cock shall be placed between this valve and the boiler. The interposition of an ordinary cock in this situation, however, involves the necessity of a safety valve being placed somewhere in the feed pipe, else the pipe will be burst, should the engine be started when the cock happens to be shut. This risk will be obviated by the use of a cock such as is shown in figs. 78, 79, and 80, in which the back-pressure valve is incorporated with the cock, and forms a part of it.

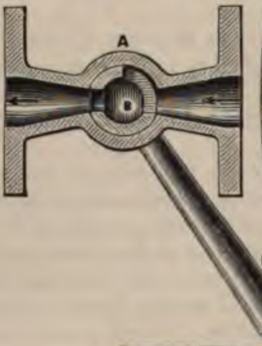


Fig. 78.—Bourne's Feed Cock. Horizontal section.

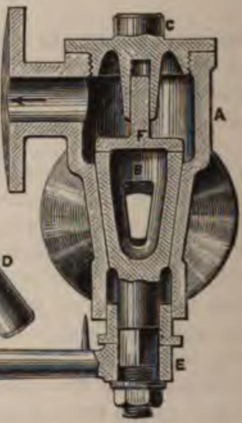


Fig. 79.—Bourne's Feed Cock. Vertical cross section.

Q. Will you describe the structure and action of this cock?

A. To do this it will be necessary to refer to the accompanying figures, where fig. 78 is a horizontal section through the cock, fig. 79 a vertical cross section, and fig. 80 a vertical longitudinal section. The same letters refer to the same parts in all the sections. A is the body of the cock, B the plug, and C a screwed cover through which the plug and the back-pressure valve F are introduced, E is the stuffing-box, and D is the handle of the cock, by which it is moved—a small pointer opposite to an index showing whether the cock is open or shut. The water passes in the direction of the arrows. In fig. 78 the cock is shown open to the overflow, and while in that position no water will enter the boiler. But if the handle be turned to the opposite side, the outlet for the water will be closed, while the inlet remains open, and in such event the water will lift the valve F, and enter the boiler through the pipe shown in section in fig. 79, with the arrow pointing in the direction in which the water flows.

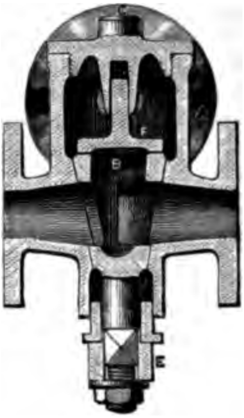


Fig. 80.—Bourne's Feed Cock. Vertical longitudinal section.

STEAM PASSAGES.

Q. What are the proper dimensions of the steam-passages?

A. In slow working engines the common size of the cylinder passages is one-twenty-fifth of the area of the cylinder, or one-fifth of the diameter of the cylinder, which is the same thing. This proportion corresponds very nearly with one square inch per nominal horse-power, when the length of the cylinder is about equal to its diameter; and one square inch of area per nominal horse-power for the cylinder ports and eduction passages answers very well in the case of engines working with a low pressure, and at the ordinary low speed of 220 feet per minute. The area of the steam pipe is usually made less than the area of the eduction pipe, especially when the engine is worked expansively, and with a considerable pressure of steam. In the case of condensing engines, however, working with the low pressure of from 4 to 8 lbs. above the atmosphere, the area of the steam pipe is not less than a circular inch per nominal horse power. In such engines the diameter of the steam pipe may be found by the following rule:—Divide the number of nominal horse-power by 0·8, and extract the square root of the quotient, which will be the internal diameter of the steam pipe.

Q. Will you explain by what process of computation these proportions are arrived at?

A. The size of the steam pipe is so regulated that there will be no material disparity of pressure between the cylinder and boiler; and in fixing the size of the eduction passage the same object is kept in view. When the diameter of the cylinder and the velocity with which the piston travels are known, it is easy to tell what the velocity of the steam in the steam pipe will be; for if the area of the cylinder be 25 times greater than that of the steam pipe, the steam in the steam pipe must travel 25 times faster than the piston, and the difference of pressure requisite to produce this velocity of the steam can easily be ascertained, by finding what height a column of steam must be to give that velocity, and what the weight or pressure is of such a column. In practice, however, this proportion is always exceeded, from the friction, and also from the condensation of steam in the pipe.

Q. If the relation you have mentioned subsist between the area of the steam-passages and the velocity of the piston, then the passages must be larger when the piston travels very rapidly?

A. And they are so made. The area of the ports of locomotive engines is usually so proportioned as to be from $\frac{1}{8}$th to $\frac{1}{6}$th the area of the cylinder; and in all high-speed engines the ports should be very large, and the valve should have a good deal of travel, so as to open the port very quickly. The area of port which it appears advisable to give to modern engines of every description is expressed by the following rule:—Multiply the area of the cylinder in square inches by the speed of the piston in feet per minute, and divide the product by 4,000; the quotient is the area of each cylinder port in square inches. This rule gives rather more than a square inch of port per nominal horse-power to condensing engines working at Watt's ordinary speed; but the excess is but small, and is upon the right side. For engines travelling very fast it gives a good deal more area than the common proportion, which is too small in nearly every case. In locomotive engines the eduction pipe passes into the chimney, and the force of the issuing steam has the effect of maintaining a rapid draught through the furnace, as before explained. The orifice of the waste steam pipe, or the blast pipe, as it is termed, is much contracted in some engines with the view of producing a fiercer draught, and an area of $\frac{1}{22}$nd of the area of the cylinder is a common proportion; but this is as much contraction as should be allowed, and is greater than is advisable.

Q. In engines moving at a high rate of speed, you have stated that it is important to give the valve lead, or, in other words, to allow the steam to escape before the end of the stroke?

A. Yes, this is very important, else the piston will have to force out the steam from the cylinder, and will be much resisted. Near the end of the stroke the piston begins to travel slowly, and if the steam be then permitted to escape, very little of the effective stroke is lost, and time is afforded to the steam, before the motion of the piston is again accelerated, to make its escape by the port. In some locomotives, from inattention to this adjustment and from a contracted area of tube section, which involved a strong blast, about half the power of the engine has been lost; but in more recent engines, by using enlarged ports and by giving sufficient lead, this loss has been greatly diminished.

Q. What do you call sufficient lead

A. In fast-going engines I would call it sufficient lead, when the eduction port was nearly open at the end of the stroke.

Q. Can you give any example of the benefit of increasing the lead?

A. The early locomotives were made with very little lead, and the proportions were, in fact, very much the same as those previously existing in land engines. About 1832, the benefits of lap upon the valve, which had been employed by Boulton and Watt more than twenty years before, were beginning to be pretty generally apprehended; and, in the following year, this expedient of economy was applied to the steamer 'Manchester,' on the Clyde, and to some other vessels, with very marked success. Shortly after this time, lap began to be applied to the valves of locomotives, and it was found that not only was there a benefit from the operation of expansion, but that there was a still greater benefit from the superior facility of escape given to the steam, inasmuch as the application of lap involved the necessity of turning the eccentric round upon the shaft, which caused the eduction to take place before the end of the stroke. In 1840, one of the engines of the Liverpool and Manchester Railway was altered so as to have 1 inch lap on the valve, and 1 inch opening on the eduction side at the end of the stroke, the valve having a total travel of $4\frac{1}{4}$ inches. The consumption of fuel per mile fell from 36·3 lbs. to 28·6 lbs., or about 25 per cent., and a softer blast sufficed. By using larger exhaust passages, larger tubes, and closer fire-bars, the consumption was subsequently brought down to 15 lbs. per mile.

AIR PUMP, CONDENSER, AND HOT AND COLD WATER PUMPS.

Q. Will you state the proper dimensions of the air pump and condenser in land and marine engines?

A. Mr. Watt made the air pump of his engine half the diameter of the cylinder and half the stroke, or one-eighth of the capacity, and the condenser was usually made about the same size as the air pump.

Q. Was this proportion found suitable in all cases?

A. In the case of the engines of paddle steamers working with little expansion it was found to be rather small.

Q. What made it too small in the case referred to?

A. The irregularity of motion caused by the roughness of the sea, in consequence of which the air pump at times moved only slowly, though the injection water was all the while running in at its accustomed speed. The water, therefore, accumulated in the condenser and ran back into the cylinder, causing fracture.

Q. Are air pumps now sometimes made double-acting?

A. Some of the direct-acting marine engines for driving the screw are fitted with a double-acting air pump, and when the air pump is double-acting, it need only be about half the size that is necessary when it is single-acting. It is single-acting in nearly every case, unless the engines are horizontal.

Q. What is the difference between a single and a double acting air pump?

A. The single-acting air pump expels the air and water from the condenser only in the upward stroke of the pump, whereas a double-acting air pump expels the air and water both in the upward and downward stroke. It has, therefore, to be provided with inlet and outlet valves at both ends, whereas the single-acting pump has only to be provided with an inlet or foot valve, as it is termed, at the bottom, and with an outlet or delivery valve, as it is termed, at

The single-acting air pump requires to be provided with a valve or valves in the piston or bucket of the pump, to enable the air and water lying below the bucket, when it begins to descend, and which have entered from the condenser during the upward stroke, to pass through the bucket into the space above it during the downward stroke, from whence they are expelled into the atmosphere on the upward stroke succeeding. But in the double-acting air pump no valve is required in the piston or bucket of the pump, and all that is necessary is an inlet and outlet valve at each end.

Q. What are the dimensions of the foot and discharge valves of the air pump?

A. The area through the foot and discharge valves is usually made equal to one-fourth of the area of the air pump, and the diameter of the waste water pipe is made one-fourth of the diameter of the cylinder, which gives an area somewhat less than that of the foot and discharge valve passages. But this proportion only applies in slow engines. In fast engines, with the air pump bucket moving as fast as the piston, the area through the foot and discharge valves should be equal to the area of the pump itself, and the waste water pipe should be of about the same dimensions.

Q. You have stated that double-acting air pumps need only be of half the size of single-acting ones. Does that relation hold at all speeds?

A. It holds at all speeds if the velocity of the pump buckets are in each case the same; but it does not hold if the engine with the single-acting pump works slowly, and the engine with the double-acting pump moves rapidly. All pumps moving at a high rate of speed lose part of their efficiency, and such pumps should therefore be of extra size.

Q. How do you estimate the quantity of water requisite for condensation?

A. Mr. Watt found that the most beneficial temperature of the hot well of his engines was 100 degrees. If, therefore, the temperature of the steam be 212°, and the latent heat 1,000°, then 1,212° may be taken to represent the heat contained in the steam, or 1,112°, if we deduct the temperature of the hot well. If the temperature of the injection water be 50°, then 50 degrees of cold are available for the abstraction of heat, and as the total quantity of heat to be abstracted is that requisite to raise the quantity of water in the steam 1,112 degrees, or 1,112 times that quantity one degree, it would raise one-fiftieth of this, or 22·24 times the quantity of water in the steam 50 degrees. A cubic inch of water, therefore, raised into steam, will require 22·24 cubic inches of water at 50 degrees for its condensation, and will form therewith 23·24 cubic inches of hot water at 100 degress. Mr. Watt's practice was to allow about a wine pint (28·9 cubic inches) of injection water for every cubic inch of water evaporated from the boiler.

Q. Is not a good vacuum in an engine conducive to increased power?

A. It is.

Q. And is not the vacuum good in the proportion in which the temperature is low, supposing there to be no air-leaks?

A. Yes.

Q. Then how could Mr. Watt find a temperature of 100° in the water drawn from the condenser to be more beneficial than a temperature of 70° or 80°, supposing there to be an abundant supply of cold water?

A. Because the superior vacuum due to a temperature of 70° or 80° involves the admission of so much cold water into the condenser, which has afterwards to be pumped out in opposition to the pressure of the atmosphere, that the gain in the vacuum does not equal the loss of power occasioned by the additional load upon the pump, and there is therefore a clear loss by the reduction of the temperature below 100, if such reduction be caused by the admission of an additional quantity of water. If the reduction of temperature, however, be caused by the use of colder water, there is a gain produced by it, though the gain will within certain limits be greater if advantage be taken of the lowness of the temperature to diminish the quantity of injection. On the whole, it is better to work engines hot, or with the water in the hot well somewhat above 100 degrees, so as to have hot water to feed the boiler.

Q. How do you determine the proper area of the injection orifice when injection is used?

A. The area of the injection orifice proper for any engine can easily be told when the quantity of water requisite to condense the steam is known, and the pressure is specified under which the water enters the condenser. The vacuum in the condenser may be taken at 26 inches of mercury, which is equivalent to a column of water 29·4 feet high, and the square root of 29·4 multiplied by 8·021 is 43·15, which is the velocity in feet per second that a heavy body would acquire in falling 29·4 feet, or with which the water would enter the condenser. Now, if a cubic foot of water evaporated per hour be equivalent to an actual horse-power, as in Watt's engines was the case, and if 28·9 cubic inches of water be requisite for the condensation of a cubic inch of water in the form of steam, 28·9 cubic feet of condensing water per horse-power per hour, or 13·905 cubic inches per second, will be necessary for the engine, and the size of the injection orifice must be such that this quantity of water flowing with the velocity of 43·15 feet per second, or 517·8 inches per second, will gain admission to the condenser. Dividing, therefore, 13·905, the number of cubic inches to be injected, by 517·8, the velocity of influx in inches per second, we get 0·02,685 for the area of the orifice in square inches; but inasmuch as it has been found by experiment that the actual discharge of water through a hole in a thin plate is only six-tenths of the theoretical discharge, on account of the contracted vein, the area of the orifice must be increased in the proportion of such diminution of effect, or be made 0·04,475, or $\frac{1}{22}$nd of a square inch per horse-power. This, it will be remarked, is the theoretical area required per actual horse-power; but as the friction and contractions in the pipe further reduce the discharge, the area was made $\frac{1}{15}$th of a square inch per actual horse-power, or rather per cubic foot of water evaporated from the boiler.

Q. Cannot the condensation of the steam be accomplished by other means than by the admission of cold water into the condenser?

A. It may be accomplished by the method of external cold, as it is called, which consists in the application of a large number of thin metallic surfaces to the condenser, on the one side of which the steam circulates, while on the other side there is a constant current of cold water, and the steam is condensed by coming into contact with the cold surfaces, without mingling with the water used for the purpose of refrigeration. The first kind of condenser employed by Mr. Watt was constructed after this fashion, but he found it in practice to be inconvenient from its size, and to become furred up or incrusted when the water was bad, whereby the conducting power of the metal was impaired. He therefore reverted to the use of the jet of cold water, as being upon the whole preferable. The jet entered the condenser instead of the cylinder, as was the previous practice, and this method is now the one in common use for land engines. But surface condensers are almost universally employed in the case of marine engines. About fifty years ago, a good number of steam vessels were fitted with Hall's condensers, which operated on the principle of external cold, and which consisted of a faggot of small copper tubes into which the steam was let surrounded by cold water; but the use of those condensers was relinquished, as no practical benefit resulted from them. Latterly, however, the plan has been revived; but it should only be used as a means of acquiring high pressures.

Q. In what way can the use of such condensers conduce to the acquisition of high pressures?

A. Because high pressures cannot be employed in the case of boilers fed with salt water, and hence, where such pressures are needed, fresh water must be employed to feed the boiler. As a supply of such water cannot be carried, it must be made by condensing the steam on the same principle as that adopted in the worm of a still. The result of such condensation is fresh or distilled water, as the salt does not pass over by distillation, but only the water.

Q. But may not the boiler be kept within permissible limits of saltness, or two salt waters, as it is called, by frequent blowing off?

A. No, not if a high pressure of steam be employed. For at a temperature exceeding that due to a pressure of 40 lbs., the sulphate of lime, which is the most mischievous ingredient in sea water, is deposited by the heat alone without concentration, as in a salt pan, and large blowing off would increase the evil by rendering it necessary to introduce large additional supplies of water from the sea, the sulphate of lime in which would be at once deposited, and so the amount of such deposit would be increased rather than diminished by large blowing off.

Q. Is there no way of obviating this result?

A. It might probably be obviated by heating the feed water in a separate vessel to the temperature of the steam before introducing it into the boiler, and interposing a filter between this vessel and the boiler, so as to separate the precipitated particles. But this plan has not yet been tried, and the remedy universally adopted is the use of surface condensers.

Q. What amount of cooling surface is required in those condensers?

A. Two-thirds of the heating surface in the boiler.

Q. You stated that the capacity of the feed pump was $\frac{1}{240}$th of the capacity of the cylinder in the case of condensing engines—the engine being double-acting and the pump single-acting—and that in high-pressure engines the capacity of the pump should be greater in proportion to the pressure of the steam. Can you give any rule that will express the proper capacity for the feed pump at all pressures?

A. That will not be difficult. In Watt's engines the pressure in the boiler may be taken at 5 lbs. above the atmospheric pressure, or 20 lbs. altogether; and as high-pressure steam is merely low-pressure steam compressed into a smaller compass, the size of the feed pump in relation to the size of the cylinder must obviously vary in the direct proportion of the pressure; and if it be $\frac{1}{140}$th of the capacity of the cylinder when the total pressure of the steam is 20 lbs., it must be $\frac{1}{70}$th of the capacity of the cylinder when the pressure is 40 lbs. per square inch, or 25 lbs. per square inch above the atmospheric pressure. This law of variation is expressed by the following rule:—Multiply the capacity of the cylinder in cubic inches by the total pressure of the steam in lbs. per square inch, or the pressure per square inch on the safety valve plus 15, and divide the product by 4,800; the quotient is the capacity of the feed pump in cubic inches, when the feed pump is single-acting and the engine double-acting. If the feed pump be double-acting, or the engine single-acting, the capacity of the pump must be just one-half of what is given by this rule

Q. But should not some addition be made to the size of pump thus obtained if the pump works at a high rate of speed?

A. No; this rule makes allowance for defective action. All pumps lift much less water than is due to the size of their barrels and the number of their strokes. Moderately good pumps lose 50 per cent. of their theoretical effect, and bad pumps 80 per cent.

Q. To what is this loss of effect to be chiefly ascribed?

A. Mainly to the inertia of the water, which, if the pump-piston be drawn up very rapidly, cannot follow it with sufficient rapidity, so that there may be a vacant space between the piston and the water; and at the return stroke the momentum of the water in the pipe expends itself in giving a reverse motion to the column of water approaching the pump. Messrs. Kirchweger and Prusman, of Hanover, have investigated this subject, by applying a revolving cock at the end of a pipe leading from an elevated cistern containing water, and the water escaped at every revolution of the cock, in the same manner as if a pump were drawing it. With a column of water of 17 feet, they found that, at 80 revolutions of the cock per minute, the water delivered per minute by the cock was 9·45 gallons; but with 140 revolutions of the cock per minute, the water delivered per minute by the cock was only 5·42 gallons. They subsequently applied an air vessel to the pipe beside the cock, when the discharge rose to 12·9 gallons per minute with 80 revolutions, and 18·28 gallons with 140 revolutions. Air vessels should therefore be applied to the suction side of fast-moving pumps, and the suction pipe should be made as short as possible.

Q. What are the usual dimensions of the cold water pump of land engines?

A. If to condense a cubic inch of water raised into steam 28·9 cubic inches of condensing water are required, then the cold water pump ought to be 28·9 times larger than the feed pump, supposing that its losses were equally great. The feed pump, however, is made sufficiently large to compensate for leaks in the boiler and loss of steam through the safety valve, so that it will be sufficient if the cold water pump be 24 times larger than the feed pump. This ratio is preserved by the following rule:—Multiply the capacity of the cylinder in cubic inches by the total pressure of the steam per square inch, or the pressure on the safety valve plus 15, and divide the product by 200. The quotient is the proper capacity of the cold water pump in cubic inches, when the engine is double-acting and the pump single-acting.

STRENGTHS OF LAND ENGINES.

Q. Can you give a rule for telling the proper thickness of the cylinders of steam engines?

A. In low-pressure engines the thickness of metal of the cylinder, in engines of a medium size, should be about $\frac{1}{40}$th of the diameter of the cylinder, which, with a pressure of steam of 20 lbs. above the atmosphere, will occasion a strain of only 400 lbs. per square inch of section of the metal; the thickness of the metal of the trunnion bearings of oscillating engines should be $\frac{1}{32}$nd of the diameter of the cylinder, and the breadth of the bearing should be about half its diameter. In high-pressure engines the thickness of the cylinder should be about $\frac{1}{16}$th its diameter, which, with a pressure of steam of 80 lbs. upon the square inch, will occasion a strain of 640 lbs. upon the square inch of section of the metal; and the thickness of the metal of the trunnion bearings of high-pressure oscillating engines should be $\frac{1}{13}$th of the diameter of the cylinder. The strength, however, is not the sole consideration in proportioning cylinders, for they must be made of a certain thickness, however small the pressure is within them, that they may not be too fragile and will stand boring. While, also, an engine of 40 inches diameter would be about one inch thick, the thickness would not be quite two inches in an 80-inch cylinder. In fact, there will be a small constant added to the thickness for all diameters, which will be relatively larger the smaller the cylinders become. In the engines of Penn's 12 horse-power engines, the diameter of cylinder being 21½ inches, the thickness of the metal is $\frac{9}{16}$ths; in Penn's 40-inch cylinders, the thickness is 1 inch; and in the engines of the 'Ripon,' 'Pottinger,' and 'Indus,' by Messrs. Miller, Ravenhill, and Co., with cylinders 76 inches diameter, the thickness of the metal was $1\frac{11}{16}$. These were all oscillating engines.

Q. What is the proportion of the piston rod in land engines?

A. The diameter of the piston rod is usually made $\frac{1}{10}$th of the diameter of the cylinder, or the sectional area of the piston rod is $\frac{1}{100}$th of the area of the cylinder. This proportion, however, is not applicable to locomotives, or even fast-moving marine engines. In locomotive engines the piston rod is made $\frac{1}{7}$th of the diameter of the cylinder, and it is obvious that where the pressure on the piston is great, the piston rod must be larger than when the pressure on the piston is small.

Q. What are the proper dimensions of the main links of a land beam engine?

A. The sectional area of the main links in land beam engines is usually made $\frac{1}{113}$th of the area of the cylinder, and the length of the main links is usually half the length of the stroke.

Q. What are the dimensions of the connecting rod of a land beam engine?

A. In land engines the connecting rod is often made of cast iron with a cruciform section; the breadth across the arms of the cross is about $\frac{1}{20}$th of the length of the rod; the sectional area at the centre $\frac{1}{28}$th of the area of the cylinder, and at the ends $\frac{1}{35}$th of the area of the cylinder; the length of the rod is usually 3½ times the length of the stroke. It is preferable, however, to make the connecting rod of malleable iron, and then the dimensions will be those proper for marine engines.

Q. What was Mr. Watt's rule for the connecting rod?

A. Some of his connecting rods were of iron and some of wood. To determine the thickness when of wood, multiply the square of the diameter of the cylinder in inches by the length of the stroke in feet, and divide the product by 24. Extract the fourth root of quotient, which is the thickness in inches. For iron the rule was the same, only the divisor was 57·6 instead of 24.

Q. What are the dimensions of the end studs of a land engine beam?

A. In low-pressure engines the diameter of the end studs of the engine beam is usually made $\frac{1}{9}$th of the diameter of the cylinder when of cast iron, and $\frac{1}{10}$th when of wrought iron, which gives a load with low steam of about 500 lbs. per circular inch of transverse section; but a larger size is preferable, as with large bearings the brasses do not wear so rapidly, and the straps are not so likely to be burst by the bearings becoming oval. These sizes, as also those which immediately follow, suppose the pressure on the piston to be 18 lbs. per circular inch.

Q. How is the strength of a cast iron gudgeon computed?

A. To find the proper size of a cast iron gudgeon adapted to sustain any given weight: Multiply the weight in lbs. by the intended length of bearing expressed in terms of the diameter; divide the product by 500, and extract the square root of the quotient, which is the diameter in inches.

Q. What was Mr. Watt's rule for the strength of gudgeons?

A. Supposing the gudgeon to be square, then, to ascertain the thickness, multiply the weight resting on the gudgeon by the distance between the trunnions, and divide the product by 333. Extract the cube root of the quotient, which is the thickness in inches.

Q. How do you find the proper strength for the cast iron beam of a land engine?

A. If the force acting at the end of an engine beam be taken at 18 lbs. per circular inch of the piston, then the force acting at the middle will be 36 lbs. per circular inch of the piston, and the proper strength of the beam at the centre will be found by the following rule:—Divide the weight in lbs. acting at the centre by 250, and multiply the quotient by the distance between the extreme centres. To find the depth, the breadth being given: Divide this product by the breadth in inches, and extract the square root of the quotient, which is the depth. The depth of a land engine beam at the ends is usually made one-third of the depth at the centre (the depth at the centre being equal to the diameter of the cylinder in the case of low-pressure engines), while the length is made equal to three times the length of the stroke, and the mean thickness $\frac{1}{108}$ of the length—the width of the edge bead being about three times the thickness of the web. In many modern engines the force acting at the end of the beam is more than 18 lbs. per circular inch of the piston, and it is now known moreover that the strength of a beam depends mainly on the strength of the flanges. It is in the flanges therefore that the strength should be chiefly collected, and they should be made much broader than the proportion usually observed in old engines.

Q. What was Mr. Watt's rule for the main beams of his engines?

A. Some of those beams were of wood and some of cast iron. The wood beams were so proportioned that the thickness was $\frac{1}{5\cdot8}$th of the circumference, and the depth $\frac{1}{3\cdot75}$. The side of the beam, supposing it square, was found by multiplying the diameter of the cylinder by the length of the stroke, and extracting the cube root of the quotient, which will be the depth or thickness of the beam. This rule allows a beam 16 feet long to bend $\frac{1}{8}$th of an inch, and a beam 32 feet long to bend $\frac{1}{4}$ of an inch. For cast iron beams the square of the diameter of the cylinder, multiplied by half the length between the centres, is equal to the square of the depth, multiplied by the thickness.

Q. Are beam engines still largely employed for driving factories and mills?

A. They have very much gone out. In small powers, high-pressure horizontal engines are mostly used, and for large powers compound engines of the marine type.

Q. What law does the strength of beams and shafts follow?

A. In the case of beams subjected to a breaking force, the strength with any given cohesion of the material will be propor-ional to the breadth, multiplied by the square of the depth; and n the case of revolving shafts exposed to a twisting strain, the rength with any given cohesive power of the material will be as e cube of the diameter.

Q. Why as the cube, seeing that the area of the metal to be ken varies as the square of the diameter?

A. Because each addition to the diameter is made at an in-sed distance from the centre of motion, and therefore, on the ciple of virtual velocities, the strain upon it will be less. For reason the strength of a hollow shaft relatively with its weight e greater than that of a solid one.

How is the strength of a cast iron shaft to resist torsion nined?

A. Experiments upon the force requisite to twist off cast iron necks show that if the cube of the diameter of neck in inches be multiplied by 880, the product will be the force of torsion which will twist them off when acting at 6 inches radius. On this fact the following rule is founded :—To find the diameter of a cast iron fly wheel shaft : Multiply the square of the diameter of the cylinder in inches by the length of the crank in inches, and extract the cube root of the product, which multiply by 0·3,025, and the result will be the proper diameter of the shaft in inches at the smallest part, when of cast iron.

Q. What was Mr. Watt's rule for the necks of his crank shafts?

A. Taking the pressure on the piston at 12 lbs. pressure on the square inch, and supposing this force to be applied at one foot radius, divide the total pressure of the piston reduced to 1 foot of radius by 31·4, and extract the cube root of the quotient, which is the diameter of the shaft : or extract the cube root of 13·7 times the number of cubic feet of steam required to make one revolution. which is also the diameter of the shaft.

MILL GEARING.

Q. With whom did the existing system of toothed mill gearing originate ?

A. Toothed wheels are a very old invention, and in a rude form have been in use in the East from time immemorial. Spiral gearing and the plan of arranging ordinary gearing in spiral steps originated with Robert Hooke, two centuries ago. But the existing system of gearing for mills was first matured and methodised by Boulton and Watt in connection with their improved steam engine.

Q. On what principle did they proceed in fixing the proportions proper for the strength of toothed wheels of cast iron ?

A. They found that a bar of cast iron 1 inch square and 12 inches long bore 600 lbs. before breaking. On the principle of virtual velocities, it would bear 1,200 lbs. if 6 inches long and 7,200 lbs. if 1 inch long. Taking the safe load at $\frac{1}{15}$th of the breaking weight, the proper load for each tooth 1 inch long will be $\frac{1}{15}$th of 7,200, or 480 lbs. for each square inch of sectional area of iron, and this Boulton and Watt took as the basis of their system. To find the number of actual horses power a wheel of any given proportions will transmit : Multiply the square of the pitch of the teeth in inches by the breadth of the wheel in inches by its diameter in feet, and by the number of revolutions it makes per minute, and divide the product by the constant number 306. The quotient is the number of actual horses power that the wheel will safely transmit, according to Boulton and Watt's practice.

Q. What do you mean by the pitch of the teeth?

A. The distance between the centre of any one tooth and the centre of the next tooth to it, measured on a circle running round the edge of the wheel midway between the top and bottom of the teeth. This circle is called the pitch circle.

Q. Can you give any practical rule for determining the strength of the teeth?

A. To find the proper dimensions for the teeth of a cast iron wheel: Multiply the diameter of the pitch circle in feet by the number of revolutions to be made per minute, and reserve the product for a divisor; multiply the number of actual horses power to be transmitted by 240, and divide the product by the above divisor, which will give the strength. If the pitch be given, to find the breadth, divide the above strength by the square of the pitch in inches; or if the breadth be given, then to find the pitch divide the strength by the breadth in inches, and extract the square root of the quotient, which is the proper pitch in inches. The breadth of the teeth measured parallel to the axis should at ordinary velocities be four times the thickness, both wheels being well greased. But for high velocities the breadth of the teeth should be five times the thickness, and six times if the teeth are constantly wet. But this extra breadth does not add to the strength, but only to the durability of the wearing surfaces. The length of the teeth is usually about ⅝ths of the pitch. Pinions to work satisfactorily should not have less than 30 or 40 teeth, and where the speed exceeds 220 feet in the minute, the teeth of the larger wheel should be of wood, made a little thicker to keep the strength unimpaired.

ROPE AND BELT GEARING.

Q. Are not ropes and belts now much used instead of toothe wheels for the transmission of power?

A. They are much used, and have many advantages, among which is the smoothness and noiselessness of their motion.

Q. What kind of ropes are used for this purpose?

A. Hempen ropes, varying from 4½ inches circumference in the case of small powers to 6½ inches circumference in the case of large powers. The ropes run in V grooves, and the engine drives a number of such ropes, each transmitting its power to the appointed place.

Q. What are the sizes of the pulleys used for this purpose?

A. The circumference of a pulley should not be less than 30 times that of the rope that drives it. The distance between the driving and driven pulley may be from 20 to 60 feet. The ropes should not bottom in the V grooves. The sides of the groove should stand at an angle of 43° with one another. It is advisable to have the driving side of each rope at the bottom, so that the returning side may lap more round its pulleys.

Q. Can you cite any example of a factory fitted with such ropes for transmitting the power to the different parts? ·

A. In a factory fitted by Messrs. Pearce, of Dundee, the engine makes 43 revolutions per minute, and generates 400 to 425 horses power. The fly-wheel is 22 feet in diameter, and 4 feet 10 inches wide, with 18 grooves in it for the reception of ropes. The power transmitted by each rope of 6½ inches circumference is 23 actual horses power. 5 ropes are led to the ground floor, where they give motion to a pulley 7 feet 6 inches diameter; 4 ropes are led to the first floor, where they drive a pulley 5 feet 6 inches diameter; and 6 ropes are led to the attic, where they drive a pulley 5 feet 6 inches diameter. On the other side of the engine shaft 3 ropes transmit 69 horses power to a pulley 7 feet 6 inches diameter in the weaving shed. The tension on each rope is 256 lbs. The breaking weight of untarred rope varies from 7,000 to 12,000 lbs. per square inch of section. In another factory the engines exert 1,000 horses power, and make 43 revolutions per minute. The fly wheel is 28 feet diameter, and 6 feet 7 inches wide on the face, with grooves for the reception of 25 ropes 6½ inches circumference. The speed of the periphery of the fly wheel is 3,764 feet per minute. 18 ropes transmit power to the right-hand, or spinning side, of the mill, and 7 to the left-hand, or weaving side. Each rope transmits 40 horses power, and the tension on each is 349 lbs.

Q. In the cases you have cited the mills are driven by an engine without the intervention of geared wheels at all, the motion being wholly communicated by ropes. Are belts also sometimes used to transmit motion in mills without the intervention of toothed wheels?

A. This is largely done, especially in America, where the use of belting for driving all the shafts of a mill is largely adopted.

The shafting itself is carefully made, and one form of coupling widely employed is represented in figs. 81 and 82. In fig. 81 we have a side view, and in fig. 82 a cross section of this coupling. There is a short piece of thick cast iron pipe D, which is slit on the one side from end to end to enable it to be tightened up, and opposite to this slit there is a keyway recessed partly into the shaft *d*, and partly into the cast iron thimble D. *m m* are two hoops, which are driven on the thimble D like the hoops of a cask, and which effectually tighten the thimble upon the shaft. But the whole of the parts are easily taken asunder, should there be any occasion to do so. The diameter of the coupling D is about twice that of the shaft *d*, and its length about four times the diameter of *d*. The breadth of each hoop *m m* is half the diameter of the shaft, and its thickness one-fourth of that diameter.

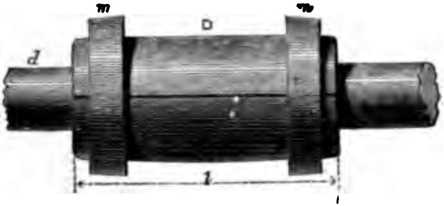


Fig. 81.—Side view of Coupling.

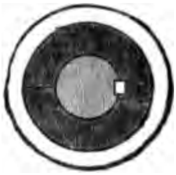


Fig. 82.—Section across Coupling.

Q. In what way are the belts led from the prime mover in the best arranged mills?

A. A large pulley or drum moved by the engine or other prime mover is placed in the basement, and two belts proceeding vertically upwards from it give motion to another great drum situated immediately above. This drum is fixed upon a shaft which runs along the centre of the overhead flat, and this shaft gives motion to pulleys right and left. The pull of the belts on one side of this centre shaft balances the pull on the other side, so that the shaft rotates in its bearings with very little friction. From the middle space between the two belts of this central drum a heavy belt is carried upwards to another drum fixed on a central shaft in the storey above, and from this central shaft belts are taken right and left to side pulleys as before, and so on until the remotest parts of the mill are reached.

Q. What should be the dimensions of such belts?

A. The two main belts proceeding from the lowest central pulley may be from 12 to 15 inches broad. These are capable of working 4,000 throstles for spinning coarse cotton yarn with preparation. The single belt proceeding from the second pulley may be 12 inches broad and somewhat thinner than the other two. It is stated that such belts are much improved by being boiled in a mixture of 2 lbs. of ordinary tallow, 1 lb. of bayberry tallow, and 1 lb. of bees wax. But the belting must be quite dry when this is done, else it will be spoiled.

Q. What are the proportions generally used in belts such as those employed for driving fans and for other similar purposes?

A. Double belts are usually made one third of an inch thick and single belts one fifth of an inch thick. The driving power of the belt is governed by its tension or tightness, and by the condition of its surface, the diameter of the pulleys having nothing to do with the matter. This tension may be increased by tightening to 350 lbs. per square inch of cross section of the belt. As a general rule, belts running from a large to a small pulley slip on the large and not on the small pulley. This is explained by the pressure per square inch on the small pulley being in the proportion in which the small pulley is less in diameter than the large one. If we cover the small pulley on the counter shaft with leather, to prevent slipping, we must also cover the driving pulley on the main shaft. These remarks apply to horizontal belts.

Q. Will you give the dimensions of belts proper for driving fans or other high-speed machines?

A. The following table is based on the law that a belt one inch wide, having a velocity of 1,000 feet per minute, will transmit one horse-power.

Proportions of Belts for driving Fans.

No. of fan	Diam. of Fan pulley	Face of pulley	Breadth of belt	Thickness of belt	Revolutions of fan per minute	Diameter of driving pulley	H. P. required
1	2⅝	2	1¾	·11	4,135	21	·5
2	3	2⅜	2	·12	3,756	24	1·
3	3½	2¾	2⅜	·13	3,250	28	1·8
4	4¼	3¼	2¾	·15	3,100	32	3·
5	4⅞	3⅞	3¼	·16	2,900	36	5·5
6	5¼	4½	3⅞	·18	2,820	42	9·7
7	6⅞	5⅛	4½	·20	2,600	48	16·
8	7⅞	6	5¼	·22	2,270	54	22·
9	9⅛	6⅞	6	·24	2,100	48	35·
10	10¼	8	7	·25	1,815	54	48·

A common rule for determining the width of a single belt $\frac{3}{16}$ths in. thick to transmit any number of horses power is to multiply the actual horse-power by 1,100 and divide by the velocity of belt in feet per minute, which gives the width in inches.

In the preceding table all the dimensions are in inches. To give some idea of the proper length of belt it may be stated that the centre of the driving pulley is placed $3\frac{1}{2}$ times its diameter from the centre of the fan, and $2\frac{1}{2}$ times above it. The driven pulley on the driving pulley shaft is 18 inches diameter, and that in turn is driven by a 54-inch pulley, and belt of double thickness. The centres of the 54-inch and 18-inch pulleys are placed about three times the diameter of the larger pulley apart, and nearly at the same height from the floor.

Q. Have new belts as much adhesion as old?

A. New belting will only transmit from one-third to one-fifth of the power without slipping that the same belts will transmit after they have been in use from one to two months. All unnecessary weight of leather in a belt is objectionable, as it tends to lift the belt off the pulley by centrifugal force when going at a great velocity, and some belts travel at a velocity of 5,000 feet per minute.

STRENGTH OF MARINE AND LOCOMOTIVE ENGINES.

Q. Cannot you give some rules for the strength of engines which will be applicable whatever pressure may be employed?

A. In the rules already given, the effective pressure may be reckoned at from 12 to 23 lbs. upon every square inch of the piston, as was long usual in land engines; and if the pressure upon every square inch of the piston be made twice greater, the dimensions taken should be those proper for an engine of twice the area of piston. It will not be difficult, however, to introduce the pressure into the rules as an element of the computation, whereby the result will be applicable both to high and low pressure engines.

Q. Will you apply this mode of computation to a side-lever marine engine, all the working parts of which are supposed to be of wrought iron, and first find the diameter of the piston rod?

A. The diameter of the piston rod may be found by multiplying the diameter of the cylinder in inches by the square root of the pressure on the piston in lbs. per square inch, and dividing by 50, which makes the strain one seventh of the elastic force, or one seventh of the force wrought iron is capable of withstanding without permanent derangement of structure, which in tensile strains is taken at 17,800 lbs. per square inch of section.

Q. What will be the rule for the connecting rod?

A. The diameter of the connecting rod at the ends may be found by multiplying 0·019 times the square root of the pressure on the piston in lbs. per square inch by the diameter of the cylinder in inches; and the diameter of the connecting rod in the middle may be found by the following rule:—To 0·0035 times the length of the connecting rod in inches add 1, and multiply the sum by 0·019 times the square root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder in inches. The strain is equal to one-sixth of the elastic force. The bottom of the connecting rod fits into a hole in the cross-tail.

Q. How do you find the diameter of the cylinder side rods of a marine engine?

A. The diameter of the cylinder side rods at the ends may be found by multiplying 0·0129 times the square root of the pressure on the piston in pounds per square inch by the diameter of the cylinder; and the diameter of the cylinder side rods at the middle is found by the following rule:—To 0·0035 times the length of the rod in inches, add 1, and multiply the sum by 0·0129 times the square root of the pressure on the piston in pounds per square inch, multiplied by the diameter of the cylinder in inches; the product is the diameter of each side rod at the centre in inches. The strain upon the side rods is by these rules equal to one-sixth of the elastic force.

Q. How do you determine the dimensions of the crank?

A. In modern screw engines the crank is often forged upon the shaft. But in some cases it is made separate, as is uniformly the case in paddle engines. To find the exterior diameter of the large eye of the crank when of malleable iron: To 1·561 times the pressure of the steam upon the piston in lbs. per square inch, multiplied by the square of the length of the crank in inches, add 0·00494 times the square of the diameter of the cylinder in inches, multiplied by the square of the number of pounds pressure per square inch on the piston; extract the square root of this quantity; divide the result by 75·59 times the square root of the length of the crank in inches, and multiply the quotient by the diameter of the cylinder in inches; square the product and extract the cube root of the square, to which add the diameter of the hole for the reception of the shaft, and the result will be the exterior diameter of the large eye of the crank when of malleable iron. The diameter of the small eye of the crank may be found by adding to the diameter of the crank pin 0·02521 times the square root of the pressure on the piston in pounds per square inch, multiplied by the diameter of the cylinder in inches.

Q. What will be the thickness of the crank web?

A. The thickness of the web of the crank, supposing it to be continued to the centre of the shaft, would at that point be represented by the following rule:—To 1·561 times the square of the length of the crank in inches, add 0·00494 times the square of the diameter of the cylinder in inches, multiplied by the pressure on the piston in pounds per square inch; extract the square root of the sum, which multiply by the diameter of the cylinder squared in inches, and by the pressure on the piston in pounds per square inch; divide the product by 9,000, and extract the cube root of the quotient, which will be the proper thickness of the web of the crank when of malleable iron, supposing the web to be continued to the centre of the shaft. The thickness of the web at the crank pin centre, supposing it to be continued thither, would be 0·022 times the square root of the pressure on the piston in pounds per square inch, multiplied by the diameter of the cylinder. The breadth of the web of the crank at the shaft centre should be twice the thickness, and at the pin centre 1½ times the thickness of the web; the length of the large eye of the crank should be equal to the diameter of the shaft, and of the small eye 0·0375 times the square root of the pressure on the piston in pounds per square inch, multiplied by the diameter of the cylinder.

Q. Will you apply the same method of computation to find the dimensions of a malleable iron paddle shaft?

A. The method of computation will be as follows:—To find the dimensions of a malleable iron paddle shaft, so that the strain shall not exceed five-sixths of the elastic force: Multiply the pressure in pounds per square inch on the piston by the square of the diameter of the cylinder in inches, and the length of the crank in inches, and extract the cube root of the product, which, multiplied by 0·08264, will be the diameter of the paddle shaft journal in inches when of malleable iron, whatever the pressure of the steam may be. The length of the paddle shaft journal should be 1¼ times the diameter; and the diameter of the part where the crank is put on is often made equal to the diameter over the collars of the bearing.

Q. How do you find the diameter of the crank pin?

A. The diameter of the crank pin in inches may be found by multiplying 0·02836 times the square root of the pressure on the piston in lbs. per square inch, by the diameter of the cylinder in inches. The length of the pin is usually about $\frac{9}{8}$th times its diameter, and the strain, if all thrown upon the end of the pin, will be equal to the elastic force; but, in ordinary working, the strain will only be equal to $\frac{1}{3}$rd of the elastic force.

Q. What are the dimensions of the cross head?

A. If the length of the cross head be taken at 1·4 times the diameter of the cylinder, the dimensions of the cross head will be as follows:—The exterior diameter of the eye in the cross head for the reception of the piston rod, will be equal to the diameter of the hole, plus 0·02827 times the cube root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder in inches; and the depth of the eye will be 0·0979 times the cube root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder in inches. The diameter of each cross head journal will be 0·01716 times the square root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder in inches—the length of the journal being $\frac{9}{8}$ths its diameter. The thickness of the web at centre will be 0·0245 times the cube root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder in inches; and the depth of web at centre will be 0·09178 times the cube root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder in inches. The thickness of the web at journal will be 0·0122 times the square root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder in inches; and the depth of the web at journal will be 0·0203 times the square root of the pressure upon the piston in lbs. per square inch, multiplied by the diameter of the cylinder in inches. In these rules for the cross head, the strain upon the web is $\frac{1}{2·225}$ times the elastic force; the strain upon the journal in ordinary working is $\frac{1}{2·33}$ times the elastic force; and if the outer ends of the journals were the only bearing points, the strain would be $\frac{1}{1·165}$ times the elastic force. But no such case can occur in practice.

Q. How do you find the diameter of the main centre?

A. The diameter of the main centre may be found by multiplying 0·0367 times the square root of the pressure upon the piston in lbs. per square inch by the diameter of the cylinder in inches, which will give the diameter of the main centre journal in inches when of malleable iron, and the length of the main centre journal should be 1½ times its diameter. The strain upon the main centre journal in ordinary working will be about ⅓ the elastic force.

Q. What are the proper dimensions of the gibs and cutters of an engine?

A. The depth of gibs and cutters for attaching the piston rod to the cross head is 0·0358 times the cube root of the pressure of the steam on the piston in lbs. per square inch, multiplied by the diameter of the cylinder; and the thickness of the gibs and cutters is 0·007 times the cube root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder. The depth of the cutter through the piston is 0·017 times the square root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder in inches; and the thickness of the cutter through the piston is 0·007 times the square root of the pressure on the piston in lbs. per square inch, multiplied by the diameter of the cylinder.

Q. Are these rules applicable to modern marine engines of the compound variety?

A. They are applicable to engines of every kind, and although side lever paddle engines are now obsolete, the rules and principles which applied to them are also applicable to all kinds of modern engines. As, however, the power of paddle engines is delivered at two points, and the power of screw engines at only one, it is expedient to make the screw shaft a good deal stronger than paddle shafts transmitting the same force or strain.

Q. Is the strain thrown upon a shaft by a pair of engines with their cranks at right angles greater than the maximum strain produced by one of the engines only, seeing that when one engine is exerting its maximum force of torsion, the other is at the dead point of the crank and not exerting any force?

A. Yes; it is greater, but not twice as great.

Q. If the cranks be at right angles, will not the maximum strain exerted by one engine correspond with the minimum strain exerted by the other engine, so that by the application of the second engine the strain will only be rendered more continuous, but will not be increased in amount?

A. It will be rendered more continuous, but will also be considerably increased in amount.

Q. Will you explain how this effect arises?

A. To do this I will take the case of an inverted compound engine with two cylinders, such as is commonly employed in screw steam vessels at the present day. The pistons, though unequal in diameter, are usually moved up and down with an equal force, the larger diameter of the low-pressure piston being compensated by the greater pressure of steam on the other.

Q. How do you estimate the efficacy of the crank in turning the shaft, supposing the pressure on the piston to be uniform?

A. In all rotative engines there will be a point in the middle of the stroke at which the crank acts with its full leverage in turning the shaft, and points at each end of the stroke at which it acts with no leverage at all, and consequently with no force whatever. In the case of an inverted engine, the effective length of the crank at each point of the stroke is measurably by the horizontal distance between the circle described by the crank pin and a vertical line carried through the centre of the shaft. This will be readily understood by a reference to fig. 83, where A B represents

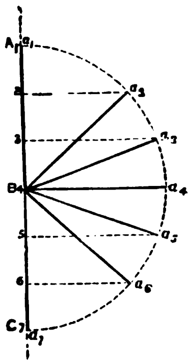


Fig. 83 — Diagram showing effectual length of crank in a single engine.

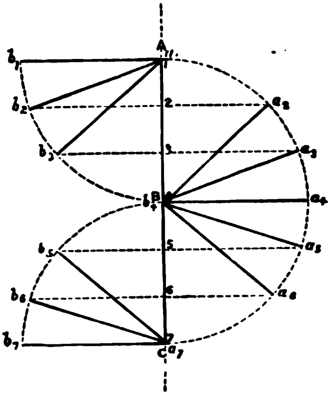


Fig. 84. – Diagram showing effectual length of crank in two engines combined.

the position of the crank when on the top centre, and B C its position when on the bottom centre. A C is consequently the length of the stroke, which may be divided into six equal heights by dotted lines, which will represent equal ascents or descents of the piston. The different corresponding positions of the crank are shown by the lines Ba_2, Ba_3, Ba_4, &c., and the corresponding effective lengths of the crank are shown by the horizontal dotted lines 2 a_2, 3 a_3, 4 a_1, &c. Supposing the length of the stroke to be 6 feet, the effective length of the horizontal crank will be 3 feet, while its effective length in the position B a_3 will be 2 feet 10 inches, and in the position B a_2 it will be 2 feet 2½ inches, these being the comparative lengths of the dotted lines.

Q. In the case of an engine with one cylinder, therefore, the force of torsion exerted upon the shaft will vary from *nil* to the full force of the piston acting at the end of a crank or lever 3 feet long. What will be the maximum and minimum strains exerted by a pair of equal engines with the cranks at right angles?

A. Here, as before, we shall best explain the position of affairs by the aid of a diagram. In fig. 84 A C is the vertical line passing through B, the centre of the shaft, and representing the length of the stroke as before. The dotted lines 2 a_2, 3 a_3, &c., represent the respective efficacies of the crank of one of the engines in its different positions and the dotted lines 2 b_2, 3 b_3, &c., represent the corresponding efficacies of the crank of the other engine in its different corresponding positions. The minimum efficacy, instead of being *nil* as before, is now equal to the maximum efficiency attained by the single engine, while the maximum efficacy of the two engines is represented by the collective lengths of each pair of horizontal dotted lines. At b_1 the effective length of one crank is *nil*, but that of the other is 3 feet. At a_4 the effective length of one crank is *nil*, while that of the other is 3 feet. At a_3 b_3 the effective length of one crank is 2 feet 10 inches, and of the other 2 feet 2½ inches, making the collective length 5 feet 0½ inches. At a_2 b_2 the effective length of one crank is 2 feet 2½ inches, and of the other 2 feet 10 inches, making the collective length 5 feet 0½ inches as before. The strain upon the shaft, therefore, by the application of a second engine is increased in the proportion of about 5 to 3.

Q. What effect is produced by the introduction of three equal engines working at equal angles?

A. With such an arrangement the force of torsion on the shaft will be exactly doubled, or the maximum will be the same as that exerted by a single piston with double the pressure upon it. This is shown by the diagram fig. 85, where B is the centre of the shaft and A C the length of the stroke as before. B a is the horizontal crank, and B b and B c the corresponding positions of the cranks of the other engines. It will be obvious from an inspection of the diagram that the effective length of the crank B *b* is represented by the dotted line B *d*, which also represents the effective length of the crank B *c*. But twice B *d* is equal to B *e*, or, in other words the joint efficiencies of these two cranks in the positions shown is equal to that of one horizontal crank. The collective efficiency of the whole combination, therefore, is equal to that of two horizontal cranks, or, in other words, the maximum force of torsion exerted by three engines in turning a shaft with their cranks placed at equal angles is equal to that exerted by two engines with their cranks horizontal, or is equal to that exerted by a single engine with twice the pressure urging the piston.

Q. In the cases you have already taken the pressure is assumed to be uniform throughout the stroke, the intention being to illustrate the various torsional efficiencies of the crank in its different positions without complicating that problem with other questions.

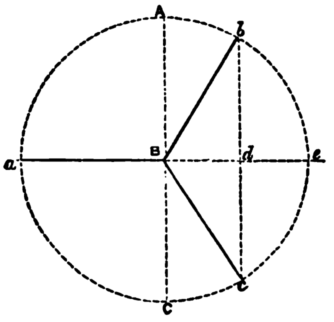


Fig. 85.—Diagram showing effectual lengths of crank with three engines set at equal angles.

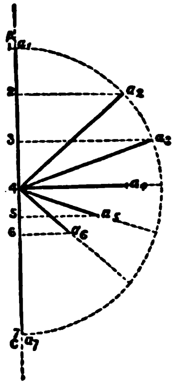


Fig. 86.—Diagram showing effective lengths of crank with steam acting expansively.

Having solved this, however, it is proper to recollect that neither in compound engines nor in modern engines of any class is there a uniform pressure maintained throughout the stroke. All modern engines act to a greater or less extent expansively, and in compound engines it is a frequent arrangement to cut off the steam from the high-pressure cylinder at one-third of the stroke, leaving it to expand three times in that cylinder, and three times more in the low-pressure cylinder or cylinders to which it is next conducted. Will you indicate in what way the introduction of the expansive principle affects the question of the maximum strain of torsion thrown upon the shaft?

A. Here, as in previous cases, we shall be aided by the introduction of a diagram, and in fig. 86 the result is shown that is produced on the force of torsion of the crank of a single engine by cutting off the steam at one-third of the stroke. It is obvious that the force of torsion will be equally reduced by diminishing the pressure of the steam or by diminishing the leverage or efficient length of the crank, and in the diagram this leverage is reduced rateably with the diminution of pressure in the cylinder so as to show the equivalent effect at one view. It will be obvious from an inspection of the diagram that the efficient lengths of the crank $2 a_2$ and $3 a_3$ for the first two-sixths or one-third of the stroke remain the same as before. But the maximum strain, instead of being at $4 a_4$ where the crank is horizontal, is at $3 a_3$ where the steam is cut off. The efficient lengths of the crank at a_5 and a_6 are also greatly reduced, and if we construct a diagram on this principle for two cylinders, we shall find that the maximum strain of torsion on the shaft from two cylinders with the steam cut off at one-third is very little more than that produced by a single engine working with full pressure throughout the stroke. This discovery warrants us in asserting that the rules heretofore in force for the strengths of single or double engines, working either without expansion or with a very limited amount of expansion, will also give adequate strength for engines, whether with two or three cylinders, working at the high rates of expansion now usual in compounds, except in the case of screw shafts, which require to be made stronger than paddle shafts, as the whole force is transmitted through them, and excepting also high speeds, where steel should be substituted for an equal area of iron, so as not merely to give strength but to prevent vibration.

Q. Will you give some examples of the application of these rules to modern compound engines, and compare the results obtained with the strengths actually adopted in one of the best examples of recent compound engines?

A. I will take for the purposes of this comparison the engines of the 'Alaska,' constructed by Messrs. John Elder & Co., this vessel having proved herself one of the most efficient on the Atlantic, and all the parts have been found to be abundantly strong. The boilers and the working parts of the engines are of steel. The pressure of steam is 100 lbs. on the square inch, and the power is generated by one high-pressure cylinder of 68 inches diameter and 6 feet stroke, and two low-pressure cylinders, each of 100 inches diameter and 6 feet stroke. Taking the vacuum in the low-pressure cylinders at 12 lbs., there must be a pressure in the receiver of about 23 lbs. to bring the force exerted by each of the low-pressure pistons up to that exerted by the high-pressure piston. Now, 100 lbs. steam − 23 lbs. back pressure = 77 lbs., which will be the effective pressure urging the high-pressure piston; and 23 lbs. steam and 12 lbs. vacuum = 35 lbs., which will be the effective pressure urging the low-pressure pistons. The area of a cylinder 68 inches diameter is 3,631·68 square inches, and the area of a cylinder 100 inches diameter is 7,854 square inches. By our rule for wrought iron piston rods the proper diameter for a cylinder 68 inches diameter and with 77 lbs. steam comes out at 11·92, and for a cylinder 100 inches diameter with 35 lbs. pressure of steam and vacuum 11·8 inches, or say 12 inches, in each case. The piston rods of the 'Alaska' are made of steel, which may be taken at twice the strength of iron. The proper diameter for a steel piston rod can manifestly be got by finding the proper diameter for an iron rod in the case of an engine with half the area of cylinder. Now, a cylinder of 48 inches diameter will have about half the area of a cylinder 68 inches diameter. The proper diameter of rod for such an engine, if made of iron, will therefore be 8·419 inches, and this will be the proper diameter for a steel rod in the case of a cylinder of 68 inches diameter and 77 lbs. effective pressure of steam. By the same process we find that the area of a cylinder 71 inches diameter is about half that of a cylinder 100 inches diameter, and that an iron rod 8·38 inches diameter is of the size proper for a 71 inch cylinder with 35 pressure per square inch on the piston. This, therefore, is the proper size of a steel rod for a 100-inch piston moving slowly. The piston rods of the 'Alaska' are each 11 inches diameter, so that, being made of steel, they afford a large margin of strength. In general it may be stated that the strengths proper for low-speed engines in iron will be those proper for high-speed engines in steel, and all modern marine compounds fall under the denomination of high-speed engines.

Q. How do the proportions of connecting rod given by the side lever rules compare with those subsisting in the 'Alaska'?

A. The two are not strictly comparable, as in a side lever engine the connecting rod is a straight rod, whereas in the 'Alaska' it is jawed to receive the end of the piston rod, and at the other end it is kept large, the better to support the butt. According to the rule given for the strengths of the parts of side lever engines the connecting rod, if made of iron, should be 11·33 inches diameter at the ends and 17 inches in the middle. In the 'Alaska' the connecting rod is 12 inches diameter below the jaw and 14 inches diameter immediately above the butt.

Q. You have stated that a screw shaft should be stronger than a paddle shaft, as the power is all given out at one point instead of being taken away at two points, as is done by paddle wheels. Should not extra strength be also given because there is only one instrument of propulsion in screw vessels, any accident occurring to which disables the vessel, while a paddle vessel may still pursue her voyage with one paddle wheel?

A. That, no doubt, is so, and the screw and screw shaft should therefore be made especially strong.

Q. You have also stated that in the case of three engines being coupled to one shaft at equal angles, the maximum strain is equal to that exerted by two single engines, each exerting its maximum strain?

A. Yes.

Q. Should not some modification, therefore, be introduced into the paddle shaft rule to make it appropriate for screw vessels?

A. No doubt.

Q. Will you explain what such modification should be?

A. We may either take an imaginary high-pressure cylinder of twice the real area, or an imaginary low-pressure cylinder with twice the real pressure, or in any other way suppose the torsional force imparted to the shaft to be doubled, and then pursue the calculation as in the rule for the strength of paddle shafts. Suppose that we elect to take double the pressure in the low-pressure cylinder, then $\sqrt[3]{70 \times 100^2 \times 36}$ multiplied by 0·08264 will give the proper diameter of the shaft. Now $70 \times 100^2 \times 36 = 25{,}200{,}000$, the cube root of which is 292; and $292 \times 0{\cdot}08264 = 24{\cdot}13$, which is the proper diameter of the screw shaft in inches, supposing it to be of wrought iron. In the 'Alaska' the screw shaft is 24 inches diameter, but it is made of steel, so that it contains a very large margin of strength. In modern engines of every kind the working parts are generally made of steel, and if the engines move at a high rate of speed, as modern engines generally do, it is proper to have a good margin of strength, not merely to obviate fracture, but to diminish vibration. Shafts of such a size as the screw shaft of the

'Alaska' should always be made hollow, as the weight may thus be greatly reduced without any diminution in the strength. Such shafts are now largely manufactured by Sir Joseph Whitworth & Co., and notwithstanding their high price are fast coming into extensive use. There appears to be no example of one of these shafts having given way. The piston rods and connecting rods might also with advantage be made hollow.

Q. In what way is the crank usually formed in the case of screw shafts?

A. It is generally cut out of the solid, and the crank pin is in such case always made of as great a diameter as the shaft, and in some cases of a somewhat greater diameter, to reduce the pressure per square inch on the surface of the bearing. Sir Joseph Whitworth & Co., however, are now making screw shafts with the cranks put on in the old fashion, and such cranks appear to be more reliable than those formed in the shaft itself.

Q. What would be the diameter of the large and small eyes of the crank if made in this manner in the case of the 'Alaska,' and what the diameter of the crank pin?

A. According to the rules already given the large eye of the crank would be 39½ inches diameter and the small eye 31¾ inches. The diameter of the crank pin would be 16¾ inches. But it would be better to make the crank pin hollow and of larger diameter.

Q. Does not the slight bending of a screw shaft between the bearings, from its own weight, somewhat increase the strain upon it?

A. It does, as also does the slight bending of the ship in a heavy sea. There are, therefore, various concurring reasons why screw shafts should be of extra strength.

CHAPTER V.

CONSTRUCTIVE DETAILS OF BOILERS.

LAND AND MARINE BOILERS.

Q. WILL you explain the course of procedure adopted by Boulton and Watt in the construction and setting of waggon boilers?

A. Most of these boilers were made of plates three-eighths of an inch thick, and the rivets were from three-eighths to three-fourths of an inch in diameter. In the bottom and sides of a waggon boiler the heads of the rivets, or the ends formed on the rivets before they are inserted, were large and placed next the fire, or on the outside; whereas on the top of the boiler the heads were on the inside. The rivets were placed about two inches distant from centre to centre, and the centre of the row of rivets was about one inch from the edge of the plate. The edges of the plates were truly cut, both inside and outside, and after the parts of the boiler had been riveted together, the edges of the plates were set up or caulked with a blunt chisel about a quarter of an inch thick in the point, and struck by a hammer of about three or four pounds weight, one man holding the caulking tool while another struck with the hammer.

Q. Is this the usual mode of caulking?

A. No, it is not the usual mode; but it is the best mode, and is the mode adopted by Mr. Watt. The usual mode is for one man to caulk the seams with a hammer in one hand and a caulking chisel in the other, and in some of the difficult corners of marine flue boilers it is not easy for two men to get in. A good deal of the caulking has also sometimes to be done with the left hand

Q. Should the boiler be proved after caulking?

A. The boiler should be filled with water and caulked afresh in any leaky part when emptied again. All the joints were painted with a solution of sal ammoniac in urine, and so soon as the seams were well rusted they were dried with a gentle fire, and then painted over with a thin putty formed of whiting and linseed oil, the heat being continued until the putty became so hard that it could not be readily scratched with the nail, and care was taken neither to burn the putty nor to discontinue the fire until it had become quite dry.

Q. How was the brickwork setting of a waggon boiler built?

A. In building the brickwork for the setting of the boiler, the parts upon which the heat acted with most intensity were built with clay instead of mortar, but mortar was used on the outside of the work. Old bars of flat iron were laid under the boiler chime to prevent that part of the boiler from being burned out, and bars of iron were also run through the brickwork to prevent it from splitting. The top of the boiler was often covered with brickwork laid in the best lime, and if the lime were not of the hydraulic kind, it was mixed with Dutch terrass to make it impenetrable to water. The top of the boiler was well plastered with this lime, which greatly conduced to the tightness of the seams. Openings into the flues were left in convenient situations to enable the flues to be swept out when required, and these openings were closed with cast iron doors jointed with clay or mortar, which could be easily removed when required. Adjacent to the chimney a slit was left in the top of the flue, with a groove in the brickwork, to enable the sliding door or damper to be fixed in that situation, which, by being lowered into the flue, obstructed the passage of the smoke and moderated the draught, whereby the chimney was prevented from drawing the flame into it before the heat had acted sufficiently upon the boiler. Waggon boilers are little used now, cylindrical boilers adapted for a higher pressure being generally preferred, and the riveting is for the most part done by the riveting machine.

Q. Are marine constructed in the same way as land boilers?

A. There is very little difference in the two cases. Even for the lowest pressures, however, the whole of the shells should be double-riveted with rivets $\frac{11}{16}$ths of an inch in diameter, and $2\frac{1}{8}$th inches from centre to centre, the weakening effect of double riveting being much less than that of single riveting. For higher pressures the butt ends of the plates should be flush, and the covering plates double with six rows of rivets, and the rivets in the rows farthest from the joint should be pitched wider apart than the others. Heavy and thick boilers should always be riveted by the riveting machine, which makes the most solid work. The tube plates of tubular boilers should be of the best Lowmoor or Bowling iron; the shells, if not steel, should be of the best Staffordshire.

Q. Of what kind of iron should the angle iron or corner iron be composed?

A. Angle iron should not be used in the construction of boilers, as in the manufacture it becomes reedy, and is apt to split up in the direction of its length. It is much the safer practice to bend the plates at the corners of the boiler; but this must be carefully done without introducing any more sharp bends than can be avoided, and plates which require to be bent much should be of Lowmoor or other iron of equal quality.

Q. Is it not important to have the holes in the plates opposite to one another?

A. In cases where the pressure is not great, or the plates very thick, the whole of the plates of a boiler should have the holes for the rivets punched, and the edges cut straight, by means of self-acting machinery, in which a travelling table carries forward the plate with an equal progression every stroke of the punch or shears; and machinery of this kind is now extensively employed. The practice of forcing the parts of boilers together with violence, by means of screw-jacks, and drifts through the holes, is never now permitted, as a great strain might thus be thrown upon the rivets, even when there was no steam in the boiler. All rivets should be of the best Lowmoor iron or of steel; and boilers formed wholly of steel are now not unusual. The edges of thick plates are now usually planed, and in many cases the whole of the rivet-holes are drilled through both plates after the plates have been put in their places. The work should be caulked both within and without wherever it is accessible. In the more confined situations within the flues the caulking will in many cases have to be done with the hand or chipping hammer, instead of the heavy hammer previously prescribed.

Q. How is the setting of marine boilers with internal furnaces effected?

A. Most marine boilers are now cylindrical, and they rest in cast-iron saddles carried by the keelsons of the vessel. In the case of rectangular boilers with flat bottoms, they were generally imbedded in mastic cement spread upon a wooden floor resting on the keelsons.

Q. How was the cement used for setting these boilers compounded?

A. Mastic cement proper for the setting of boilers is sold in many places ready made. Hamelin's mastic is compounded as follows:—To any given weight of sand or pulverised earthenware add two-thirds such given weight of powdered Bath, Portland, or other similar stone, and to every 560 lbs. weight of the mixture add 40 lbs. weight of litharge, 2 lbs. of powdered glass or flint, 1 lb. of minium, and 2 lbs. of grey oxide of lead; pass the mixture through a sieve, and keep it in a powder for use. When wanted for use, a sufficient quantity of the powder is mixed with some vegetable oil upon a board or in a trough in the manner of mortar, in the proportion of 605 lbs. of the powder to 5 gallons of linseed, walnut, or pink oil, and the mixture is stirred and trodden upon until it assumes the appearance of moistened sand, when it is ready for use. The cement should be used on the same day as the oil is added, else it will set into a solid mass.

Q. What is the best length of the furnaces of marine boilers?

A. It has already been stated that furnace bars should never exceed five feet in length, and are better made shorter, as it is difficult to manage long furnaces. If the furnaces are long and narrow, it is impossible to keep the bars covered with fire at the after end, especially upon long voyages and in stormy weather, and air escapes into the flues at the after end of the bars, whereby the efficacy of the boiler is diminished. Where the bars are very long it will generally be found that an increased supply of steam and a diminished consumption of coal will be the consequence of shortening them, and the bars should always lie with a considerable inclination to facilitate the distribution of the fuel over the after part of the furnace. When there are two lengths of bars in the furnace, it is expedient to make the central cross bar for bearing up the ends double, and to leave a space between the ends of the bars so that the ashes may fall through between them. The space thus left enables the bars to expand without injury on the application of heat, whereas without some such provision the bars are very liable to get burned out by bending up in the centre, or at the ends, as they must do if the elongation of the bars on the application of heat be prevented; and this must be the effect of permitting the spaces at the ends of the bars to be filled up with ashes. At each end of each bed of bars it is expedient to leave a space which the ashes cannot fill up so as to cause the bars to jam;

and care must be taken that the heels of the bars do not come against any of the furnace bearers, whereby the room left at the end of the bars to permit the expansion would be rendered of no avail.

Q. Have you any remarks to offer respecting the construction and arrangement of the furnace bridges and dampers of marine boilers?

A. The furnace bridges of marine boilers are walls or partitions built up at the ends of the furnaces to narrow the opening for the escape of heat into the flues. They are either made of fire brick or of plate iron containing water: in the case of water bridges, the top part of the bridge should be made with a large amount of slant so as to enable the steam to escape freely, but notwithstanding this precaution the plates of water bridges are apt to crack at the bend, so that fire brick bridges appear on the whole to be preferable. In shallow furnaces the bridges often come too near the furnace top to enable a man to pass over them; and it will save expense if in such bridges the upper portion is constructed of two or three fire blocks, which may be lifted off when a person requires to enter the flues to sweep or repair them, whereby the perpetual demolition and reconstruction of the upper part of the bridge will be prevented.

Q. What is the benefit of bridges?

A. Bridges are found in practice to have a very sensible operation in increasing the production of steam, and in some boilers in which the brick bridges have been accidentally knocked down by the firemen, a very considerable diminution in the supply of steam has been experienced. Their chief operation seems to lie in concentrating the heat within the furnace to a higher temperature, whereby the combustion is improved, and the heat, being greater, is more rapidly transmitted from the furnace to the water, so that less heat has to be absorbed by the flues. In this way the bridges render the heating surface of a boiler more effective, or enable a smaller amount of heating surface to suffice.

Q. Are the bridges behind the furnaces the only bridges used in steam boilers?

A. In former times it was not an uncommon practice to place a hanging bridge, consisting of a plate of iron descending a certain distance into the flue, at that part of the flue where it entered the chimney, whereby the stratum of hot air which occupied the highest part of the flue was kept in protracted contact with the boiler, and the cooler air occupying the lower part of the flue was that which alone escaped. But this plan was only applicable to flue boilers. In tubular boilers a hanging bridge of this kind is not applicable, but in some cases a perforated plate was placed against the ends of the tubes, which was made to operate as a sliding damper which partially or totally closed up the end of every tube, and at other times a damper constructed in the manner of a venetian blind was employed in the same situation. These varieties of damper, however, have only yet been used in locomotive boilers, and in them only to a very limited extent. But they are applicable to tubular boilers of every description.

Q. Is it a benefit to keep the flues or tubes appertaining to each furnace distinct?

A. In a flue boiler this cannot be done, but in a tubular boiler it is an advantage that there should be a division between the tubes pertaining to each furnace, so that the smoke of each furnace may be kept apart from the smoke of the furnace adjoining it until the smoke of both enters the chimney, as by this arrangement a furnace only will be rendered inoperative in cleaning the fires instead of a boiler, and the tubes belonging to one furnace may be swept if necessary at sea without interfering injuriously with the action of the rest. But in the cylindrical marine boilers now in common use this separation cannot be easily made, and is seldom carried out. In a steam vessel it is necessary at intervals to empty out one or more furnaces every watch to get rid of the clinkers which would otherwise accumulate in them; and it is advisable that the connection between the furnaces should be such that this operation, when being performed on one furnace, shall injure the action of the rest as little as possible.

Q. Can any constructive precautions be taken to prevent the furnaces and tube plates of the boiler from being burned by the intensity of the heat?

A. The sides of the internal furnaces or flues in all rectangular boilers should be so constructed that the steam may readily escape from their vertical surfaces, with which view it is expedient to make the bottom of the flue somewhat wider than the top, or slightly conical in the cross section; and the upper plates should always be overlapped by the plates beneath, so that the steam cannot be retained in the overlap, but will escape as soon as it is generated. If the sides of the furnace be made high and perfectly vertical, they will speedily be buckled and cracked by the heat, as a film of steam in such a case will remain in contact with the iron, which will prevent the access of the water, and the iron of the boiler will be injured by the high temperature it must in that case acquire. oT moderate the intensity of the heat acting upon the furnace sides, it is expedient to bring the outside fire-bars into close contact with the sides of the furnace, so as to prevent the entrance of air through the fire in that situation, by which the intensity of the heat would be increased. The tube plate nearest the furnace in tubular boilers should also be so inclined as to facilitate the escape of the steam; and the short, bent plate or flange of the tube plate, connecting the tube plate with the top of the furnace, should be made with a gradual bend, as, if the bend be sudden, the iron will be apt to crack or burn away from the concretion of salt, should sea water be at any time necessary, as may sometimes happen, even in vessels fitted with surface condensers.

Q. In what manner is the tubing of boilers performed?

A. The tubes of marine boilers are generally iron tubes, three inches in diameter, and between five and seven feet long; but sometimes brass tubes of similar dimensions are employed. When brass tubes are employed the use of ferules driven into the ends of the tubes is sometimes employed to keep them tight; but when the tubes are of malleable iron, of the thickness of Russell's boiler tubes, they may be made tight merely by driving them firmly into the tube plates, and then widening them by an expanding mandril. The same may be done with thick brass tubes. The holes in the tube plate next the front of the boiler are just sensibly larger in diameter than the holes in the other tube plate, and the holes upon the outer surfaces of both tube plates are very slightly countersunk. The whole of the tubes are driven through both tube plates from the front of the boiler,—the precaution, however, being taken to drive them in gently at first with a light hand hammer, until the whole of the tubes have been inserted to an equal depth, and then they may be driven up by degrees with a heavy hammer, whereby any distortion of the holes from unequal driving will be prevented. Finally, the ends of the tubes should be riveted up so as to fill the countersink. The tubes should be left a little longer than the distance between the outer surfaces of the tube plates, so that the countersink at the ends may be filled by staving up the end of the tube rather than by riveting it over; and the staving will be best accomplished by means of a mandril with a collar upon it, which is driven into the tube so that the collar rests upon the end of the tube to be riveted; or a tool like a blunt chisel with a recess in its point may be used, as is often done.

Q. Should not stays be introduced in substitution of some of the tubes?

A. It appears expedient in all cases that some of the tubes should be screwed at the ends, so as to serve as stays if the riveting at the tube ends happens to be burned away, and also to act as abutments to the riveted tube. These stay tubes should have nuts at each end, both within and without the tube plates, which nuts should be screwed up, with white lead interposed, before the other tubes are inserted. The nuts should be fitted very accurately to the tube plate by filing and scraping before the white lead is introduced, as, if this be omitted, they will be sure to leak. If the tubes are long, their expansion when the boiler is being blown off will be apt to start them at the ends, unless very securely fixed; and it is difficult to prevent brass tubes of large diameter and proportionate length from being started at the ends, even when secured by ferules; but the brass tubes commonly employed are so small as to be susceptible of sufficient compression endways by the adhesion due to the ferules to compensate for the expansion, whereby they are prevented from starting at the ends. In some of the early marine boilers fitted with brass tubes, a galvanic action at the ends of the tubes was found to take place, and the iron of the tube plates was wasted away in consequence with rapidity; but further experience proved the injury to be attributable chiefly to imperfect fitting, whereby a leakage was caused that induced oxidation. When the tubes were well fitted any injurious action at the ends was found to cease.

Q. What is the best mode of constructing the chimney and the parts in connection therewith?

A. In sea-going steamers the funnel plates are usually about nine feet long and $\frac{3}{16}$ths thick; and where different flues or boilers have their debouch in the same chimney, it is expedient to run division plates up the chimney for a considerable distance, to keep the draughts distinct. The waste steam pipe should be of the same height as the funnel, so as to carry the waste steam clear of it, for if the waste steam strikes the funnel it will wear the iron into holes; and the waste steam pipe should be made at the bottom with a faucett joint, to prevent the working of the funnel, when the vessel rolls, from breaking the pipe at the neck. There should be two hoops round the funnel, for the attachment of the funnel shrouds, instead of one, so that the funnel may not be carried overboard if one hoop breaks, or if the funnel breaks at the upper hoop from the corrosive action of the waste steam, as sometimes happens. The deck over the steam chest should be formed of an iron plate supported by angle iron beams, and there should be a high angle iron cooming round the hole in the deck through which the chimney ascends, to prevent any water upon the deck from leaking down upon the boiler. Around the lower part of the funnel there should be a sheet iron casing to prevent any inconvenient dispersion of heat in that situation, and another short piece of casing, of a somewhat larger diameter and riveted to the chimney, should descend for a short distance over the first casing, so as to prevent the rain or spray which may beat against the chimney from being poured down within the casing upon the top of the boiler. The pipe for conducting away the waste water from the top of the safety-valve should lead overboard, and not into the bilge of the ship, as inconvenience arises from the steam occasionally passing through it, if it has its termination in the engine room. But the precautions to be taken against waste steam are now less necessary than formerly, as with surface condensers there should be no waste steam, as a waste of steam implies a waste of water.

Q. Are not the chimneys of some vessels made so that they may be lowered when required?

A. The chimneys of small river vessels which have to pass under bridges are generally formed with a hinge, so that they may be lowered backwards when passing under a bridge; and the chimneys of some screw vessels are made so as to shut up like a spyglass when the fires are put out and the vessel is navigated under sails. A very good example of this species of chimney is that designed by Mr. Taplin and represented in fig. 87. In smaller vessels, however, two lengths of chimney suffice; and in that case there is a standing piece on deck, which however, does not project above the bulwarks.

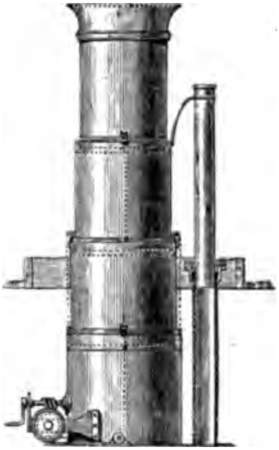


Fig. 87.—Telescope Chimney.

Q. Will you explain any further details in the construction of marine boilers which occur to you as important?

A. The man-hole and mud-hole doors, unless put on from the outside like a cylinder cover with a great number of bolts, should be put on from the inside with cross bars on the outside, and the bolts should be strong, and have coarse threads and square nuts so that the threads may not be overrun, nor the nuts become round, by the unskilful manipulations of the firemen, by whom these doors are removed or replaced. It is very expedient that sufficient space should be left between the furnace and the tubes in all tubular boilers to permit a boy to go in to clear away any scale that may have formed, and to hold on the rivets in the event of repair being wanted; and it is also expedient that a vertical row of tubes should be left out opposite to each water space to allow the ascent of the steam and the descent of the water, as it has been found that the removal of the tubes in that position, even in a boiler with deficient heating surface, has increased the production of steam, and diminished the consumption of fuel. The tubes should all be kept in the same vertical line, so as to permit the introduction of an instrument to scrape them; and the tubes should not be placed too close together, else their heating efficacy will be impaired.

INCRUSTATION AND CORROSION OF BOILERS.

Q. What is the cause of the formation of scale in marine boilers?

A. Scale is formed in all boilers which contain earthy or saline matters, just in the way in which a stony deposit, or rock, as it is sometimes termed, is formed in a tea-kettle. In sea-water the chief ingredient is common salt, which exists in solution: the water admitted to the boiler is taken away in the shape of steam, and the saline matter which is not vapourisable would, if the process were continued, accumulate in time in the boiler, until its amount became so great that the water would be saturated, or unable to hold any more in solution. The salt would then be precipitated and form a deposit which hardens by heat. The formation of scale, therefore, is similar to the process of making salt from sea-water by evaporation, the boiler being, in fact, a large salt pan.

Q. But is the scale soluble in fresh water like the salt in a salt pan?

A. No it is not; or, if soluble at all is only so to a very limited extent. The several ingredients in sea-water begin to be precipitated from solution at different degrees of concentration; and the sulphate and carbonate of lime, which begin to be precipitated when a certain state of concentration is reached, enter largely into the composition of scale, and give it its insoluble character. Pieces of waste or other similar objects left within a marine boiler appear, when taken out, as if they had been petrified; and the scale deposited upon the flues of a marine boiler using salt water resembles layers of stone.

Q. Is much inconvenience experienced in marine boilers from these incrustations upon the flues?

A. Incrustation in boilers at one time caused much more perplexity than it does at present, as it was supposed that in some seas it was impossible to prevent the boilers of a steamer from becoming salted up; but it has now been satisfactorily ascertained that there is very little difference in the saltness of different seas, and that, however salt the water may be, low-pressure boilers will be preserved from any injurious amount of incrustation by blowing off very frequently, or by permitting a considerable portion of the supersalted water to escape at short intervals into the sea. If blowing off be sufficiently practised, the scale upon the flues will never be much thicker than a sheet of writing paper, and *no excuse* should be accepted from engineers for permitting a low-pressure boiler to be damaged by the accumulation of calcareous deposit.

Q. What is the temperature at which sea-water boils in a steam boiler?

A. Sea-water contains about $\frac{1}{33}$rd its weight of salt, and in the open air it boils at the temperature of 213·2°; if the proportion of salt be increased to $\frac{2}{33}$rds of the weight of the water, the boiling point will rise to 214·4°; with $\frac{3}{33}$rds of salt the boiling point will be 215·5°; $\frac{4}{33}$rds, 216·7°; $\frac{5}{33}$rds, 217·9°; $\frac{6}{33}$rds, 219°; $\frac{7}{33}$rds, 220·2°; $\frac{8}{33}$rds, 221·4°; $\frac{9}{33}$rds, 222·5°; $\frac{10}{33}$rds, 223·7°; $\frac{11}{33}$rds, 224·9°; and $\frac{12}{33}$rds, which is the point of saturation, 226°. In a steam boiler the boiling points of water containing these proportions of salt must be higher, as the elevation of temperature due to the pressure of the steam has to be added to that due to the saltness of the water: the temperature of steam at the atmospheric pressure being 212°, its temperature, at a pressure of 15 lbs. per square inch above the atmosphere, will be 250°, and adding to this 4·7° as the increased temperature due to the saltness of the water when it contains $\frac{4}{33}$rds of salt, we have 254·7° as the temperature of the water in the boiler, when it contains $\frac{4}{33}$rds of salt and the pressure of the steam is 15 lbs. on the square inch.

Q. What degree of concentration of the salt water may be safely permitted in a low-pressure boiler?

A. It is found by experience that when the concentration of the salt water in a boiler is prevented from exceeding that point at which it contains $\frac{2}{33}$rds its weight of salt, no injurious incrustation will take place, and as sea-water contains only $\frac{1}{33}$rd of its weight of salt, it is clear that it must be reduced by evaporation to one-half of its bulk before it can contain $\frac{2}{33}$rds of salt; or, in other words, a boiler must blow out into the sea one-half of the water it receives as feed, in order to prevent the water from rising above $\frac{2}{33}$rds of concentration, or 8 ounces of salt to the gallon.

Q. How do you determine 8 ounces to the gallon to be equivalent to twice the density of salt water, or 'two salt waters,' as it is sometimes called?

A. The density of the water of different seas varies somewhat. A gallon of fresh water weighs 10 lbs.; a gallon of salt water from the Baltic weighs 10·15 lbs.; a gallon of salt water from the Irish Channel weighs 10·28 lbs.; and a gallon of salt water from the Mediterranean 10·29 lbs. If we take an average saltness represented by a weight of 10·25 lbs., then a gallon of water concentrated to twice this saltness will weigh 10·5 lbs., or the salt in it will weigh ·5 lbs. or 8 oz., which is the proportion of 8 oz. to the gallon. However, the proportion of $\frac{2}{33}$rds gives a greater proportion than 8 oz. to the gallon, for $\frac{2}{33} = \frac{1}{16}$ nearly, and $\frac{1}{16}$ of 10 lbs. = 10 oz. By keeping the density of the water in a marine boiler at the proportion of 8 or 10 oz. to the gallon, no inconvenient amount of scale will be deposited on the flues or tubes, provided the boiler is a low-pressure one. But if the pressure exceeds 40 lbs. per square inch no amount of blowing off will keep the boiler free from scale. The bulk of water, it may be remarked, is not increased by putting salt in it up to the point of saturation, but only its density is increased.

Q. Is there not a great loss of heat by blowing-off so large a proportion of the heated water from the boiler?

A. The loss is not very great. Low-pressure boilers are sometimes worked at a saltness of $\frac{4}{33}$rds, and taking this saltness and supposing the latent heat of steam to be at 1,000° at the temperature of 212°, and reckoning the sum of the latent and sensible heats as forming a constant quantity, the latent heat of steam at the temperature of 250° will be 962°, and the total heat of the steam will be 1,212° in the case of fresh water; but as the feed water is sent into the boiler at the temperature of 100°, the accession of heat it receives from the fuel will be 1,112° in the case of fresh water, or 1,112° increased by 2·23° in the case of water containing $\frac{4}{33}$rds of salt—2·23 being the 4·70° increase of temperature due to the presence of $\frac{4}{33}$rds of salt, multiplied by 0·475, the specific heat of steam. This makes the total accession of heat received by the steam in the boiler equal to 1,114·23°, or say 1,114°, which multiplied by 3, as 3 parts of the water are raised into steam, gives us 3,342° for the heat in the steam, while the accession of heat received in the boiler by the 1 part of residual brine will be 154·7°, multiplied by 0·85, the specific heat of the brine, or 130·495°; and 3,342° divided by 130·495° is about $\frac{1}{20}$th. It appears, therefore, that by blowing-off the boiler to such an extent that the saltness shall not rise above what answers to $\frac{4}{33}$rds of salt, about $\frac{1}{20}$th of the heat is blown into the sea. This is but a small proportion; and as there will be a greater waste of heat, if from the existence of scale upon the flues the heat can be only imperfectly transmitted to the water, there cannot be even an economy of fuel in niggard blowing-off, while it involves the introduction of other evils. The proportion of $\frac{4}{33}$rds of saltness, however, or 16 oz. to the gallon, is larger than is advisable, however low the pressure, especially as it is difficult to keep the saltness at a perfectly uniform point, and the working point should, therefore, be $\frac{2}{33}$rds, as before prescribed.

Q. Have no means been devised for turning to account the heat contained in the brine which is expelled from the boiler?

A. To save a part of the heat lost by the operation of blowing-off, the hot brine is sometimes passed through a number of small tubes surrounded by the feed water; but there is no very great gain from the use of such apparatus, and the tubes are apt to become choked up, whereby the safety of the boiler may be endangered by the injurious concentration of its contents. Pumps, worked by the engine for the extraction of the brine, are generally used in connection with the small tubes for the extraction of the heat from the supersalted water; and if the tubes become choked the pumps will cease to eject the water, while the engineer may consider them to be all the while in operation.

Q. What is the usual mode of blowing-off the supersalted water from the boiler?

A. The general mode of blowing-off the boiler is to allow the water to rise gradually for an hour or two up to the highest working level, and then to open the cock communicating with the sea, and keep it open until the surface of the water within the boiler has fallen several inches ; but in some cases a cock of smaller size is allowed to run water continuously, and in other cases brine pumps are used as already mentioned. In every case in which the supersalted water is discharged from the boiler in a continuous stream, a hydrometer or salt gauge of some convenient construction should be applied to the boiler, so that the density of the water may at all times be visible, and immediate notice be given of any interruption of the operation. Various contrivances have been devised for this purpose, the most of which operate on the principle of a hydrometer. Another device would be that of a differential steam gauge, which would indicate the difference of pressure between the steam in the boiler and the steam of a small quantity of fresh water enclosed in a suitable vessel, and immerged in the water of the boiler.

Q. What is the advantage of blowing off from the surface of the water in the boiler?

A. Blowing-off from a point near the surface of the water is more beneficial than blowing off from the bottom of the boiler. Solid particles of any kind, it is well known, if introduced into boiling water, will lower the boiling point in a slight degree, and the steam will chiefly be generated on the surface of the particles, and indeed will have the appearance of coming out of them. If the particles be small, the steam generated beneath and around them will balloon them to the surface of the water, where the steam will be liberated and the particles will descend ; and the impalpable particles in a marine boiler, which by their subsidence upon the flues concrete into scale, are carried in the first instance to the surface of the water, so that if they be caught there and ejected from the boiler, the formation of scale will be prevented.

Q. Are there any plans in operation for taking advantage of this property of particles rising to the surface?

A. In some boilers sheet iron vessels, called sediment collectors, are employed, which collect into them the impalpable matter. One of these vessels, of about the size and shape of a loaf of sugar, is put into each boiler with the apex of the cone turned downwards into a pipe leading overboard, for conducting the sediment away from the boiler. The base of the cone stands some distance above the water line, and in its sides conical slits are cut, so as to establish a free communication between the water within the conical vessel and the water outside it. The particles of stony matter, which are ballooned to the surface by the steam in every other part of the boiler, subside within the cone, where, no steam being generated, the water is consequently tranquil; and the deposit is discharged overboard by means of a pipe communicating with the sea. By blowing-off from the surface of the water, the requisite cleansing action is obtained with less waste of heat; and where the water is muddy, the foam upon the surface of the water is ejected from the boiler, thereby removing one of the chief causes of priming.

Q. What is the cause of the rapid corrosion of marine boilers?

A. Marine boilers were formerly corroded externally in the region of the steam chest by the dripping of water from the deck, which being of wood, it was difficult to keep tight when exposed to the heat of the boiler; the bottom of the boiler is corroded by the action of the bilge water, and the ash-pits by the practice of quenching the ashes with salt water. These sources of injury, however, admit of easy remedy.

Q. Are not marine boilers subject to internal corrosion?

A. Yes; the greatest part of the corrosion of a boiler takes place in the inside, and in the boilers which were in use when the first edition of this work appeared, the chief seat of such corrosion was the interior of the steam chest. The origin of this corrosion was then one of the obscurest subjects in the whole range of engineering. It could not be from the chemical action of the salt water upon the iron, for the flues and other parts of the boiler beneath the water suffered very little from corrosion; and in steam vessels provided with Hall's condensers, which supplied the boiler with fresh water, not much increased durability of the boiler was experienced. Nevertheless, at that time marine boilers seldom lasted more than for five or six years, whereas land boilers made of the same quality of iron often lasted eighteen or twenty years, and it did not appear probable that land boilers would last a very much shorter time if salt water were used in them. The thin film of scale spread over the parts of a marine boiler situated beneath the water effectually protected them from corrosion; and when the other parts were completely worn out the flues generally remained so perfect, that the hammer-marks upon them were as conspicuous as at their first formation. The operation of the steam in corroding the interior of the boiler was most capricious, the parts which were most rapidly worn away in one boiler being untouched in another; and in some cases one side of a steam chest was very much wasted away, while the opposite side remained uninjured. Sometimes the iron exfoliated in the shape of a black oxide which came away in flakes like the leaves of a book, while in other cases the iron appeared as if eaten away by a strong acid which had a solvent action upon it. The application of felt to the outside of a boiler had in several cases been found to accelerate sensibly its internal corrosion. Boilers in which there was a large accumulation of scale appeared to be more corroded than where there was no such deposit; and where the funnel passed through the steam chest, the iron of the steam chest was invariably much more corroded than where the funnel did not pass through it.

Q. Could you suggest no reason for the rapid internal corrosion of marine boilers?

A. The facts which I have enumerated appeared to indicate that the internal corrosion of the marine boilers of that day was attributable chiefly to the existence of superheated steam within them, which is steam to which an additional quantity of heat has been communicated subsequently to its generation, so that its temperature is greater than is due to its elastic force; and on this hypothesis the observed facts relative to corrosion became explicable. Felt, applied to the outside of a boiler, accelerated its internal corrosion by keeping the steam in a surcharged state, when by the dispersion of a part of the heat it would cease to be in that state; boilers in which there was a large accumulation of scale must have worked with the water very salt, which necessarily produced surcharged steam; for the temperature of steam cannot be less than that of the water from which it is generated, and inasmuch as the boiling point of water under any given pressure rises with the saltness of the water, the temperature of the steam must rise with the saltness of the water, the pressure remaining the same; or, in other words, the steam must have had a higher temperature than was due to its elastic force, or have been in the state of surcharged steam. The circumstance of the chimney passing through the steam will manifestly surcharge the steam with heat, so that all the circumstances which were found to accelerate corrosion were, it appeared, such as would also induce the formation of surcharged steam.

Q. Is it the natural effect of surcharged steam to waste away iron?

A. It is the natural effect of surcharged steam to oxidate the iron with which it is in contact, as is illustrated by the familiar process for making hydrogen gas by sending steam through a red hot tube filled with pieces of iron ; and although the action of the surcharged steam in a boiler is necessarily very much weaker than where the iron is red hot, it manifestly must have *some* oxidising effect, and the amount of corrosion produced may be very material where the action is perpetual. Boilers with a large extent of heating surface, or with descending flues circulating through the cooler water in the bottom of the boiler before ascending the chimney, will be less corroded internally than boilers in which a large quantity of the heat passes away in the smoke ; and the corrosion of the boiler will be diminished if the interior of any flue passing through the steam be lined with fire brick, so as to prevent the transmission of the heat in that situation. The best practice, however, appears to consist in the transmission of the smoke through a suitable passage on the outside of the boiler, so as to supersede the necessity of carrying any flue through the steam at all. It was consequently suggested in the early editions of this work that the practice of carrying the chimney through the steam chest, as was then the usual mode, should be abandoned, and this has now been universally done.

Q. But does not internal corrosion still occur in marine boilers, even when fed by fresh water obtained by surface condensation ?

A. It does. But it occurs in a different situation and from a totally different cause from that just defined. Formerly the internal corrosion was wholly above the water, now it is wholly beneath it. Formerly the source of injury lay in the corrosive action of the steam ; now it lies in the corrosive action of the water.

Q. What, then, is the cause of this corrosive action ? Is not the boiler now fed with distilled water ? and is not distilled water pure and free from corrosive activity ?

A. To this I answer that, although the boiler is fed with distilled water, it does not follow, nor is it the case, that this water is pure, seeing that it is contaminated by the oil employed for the lubrication of the pistons. This oil comes over to some extent with the water, and many kinds of this oil generate an acid within the boiler, which attacks and pits the iron. Moreover, it is not to be assumed that pure water is necessarily devoid of all corrosive activity, as it is well known that pure water will attack lead pipes, and the purer the water the more active the corrosion. In the case of iron, however, this action does not take place.

Q. What, then, is the proper remedy for this internal corrosion ?

A. The first indication is to use an oil which will not generate an acid. The second is to neutralise such acid as may be formed by a suitable alkali; and the last is to provide that such oxidation as nevertheless occurs shall be expended on the corrosion of removable pieces of zinc, whereby the iron of the boiler will be protected.

Q. Will you explain how these principles are to be practically carried out?

A. Mineral oil does not generate an acid. Vegetable oil does. But mineral oil has also its inconveniences, one of which is that it acts upon the india-rubber valves of the air pump and feed pump; and another is that it has in some cases been found to occasion a carbonaceous deposit on the tube plates of the boiler, hindering the transmission of heat and causing the tubes to leak. A mixture of mineral and vegetable oils is widely used. But for the carbonaceous deposit, it would be the best course to use mineral oil exclusively for lubricating the piston, and to supersede the india-rubber discs in the pumps by slide valves. But if Perkins' metal be used for the piston rings, all oils for the piston may, it is said, be dispensed with. The alkali usually introduced into the boiler to neutralise any acid which may be generated there is soda. To protect the iron of the boiler should acid nevertheless exist, bars of zinc are attached to those parts where oxidation is found most to occur, care being taken to make the contact between the iron and the zinc sufficiently intimate to enable a galvanic current to be permanently maintained. The zinc being the more oxidisable metal, all the oxidation which would otherwise set in upon the iron is transferred to the zinc, and the boiler is thus protected. In modern boilers it will be proper to adopt all of these expedients if oil be used. But the best solution of the difficulty will be to use the Perkins metal for the cylinder rings, if on more extended trial it is found that by the use of this metal the lubrication of the piston by oil or grease of any kind can be dispensed with. Tallow is objectionable as a lubricant, not merely because it generates an acid in the boiler, but because it carbonises the piston and congeals in the condenser tubes, choking them up.

Q. In steam vessels are there usually several boilers?

A. Yes, in steam vessels of considerable power and size.

Q. Are these boilers generally so constructed that any one of them may be thrown out of use?

A. Marine boilers are now generally supplied with stop valves, whereby one boiler may be thrown out of use without impairing the efficacy of the remainder. These stop valves are usually spindle valves of large size, and they are for the most part set in a pipe which runs across the steam chests, connecting the several boilers together. The spindles of these valves should project through stuffing boxes in the covers of the valve chests, and they may be balanced by a weighted lever, kept in continual action by the steam. If the valves be suffered to remain long stationary they will become fixed by corrosion, and it will be impossible after some time to shut them on an emergency. These valves should always be easily accessible from the engine room; and it ought not to be necessary for the coal boxes to be empty to gain access to them.

Q. Should each boiler have at least one safety valve for itself?

A. Yes; it would be quite unsafe without this provision, as the stop valve might possibly jam; or, if of the kind which is shut against the pressure by a screw, it may be accidentally left shut, as was done in the case of the 'Thunderer.' Sometimes valves jam from a distortion in the shape of the boiler, when a considerable pressure is put upon it. This was the cause of the explosion in the 'Archimedes.'

Q. How is the admission of the water into the boiler regulated?

A. The admission of feed water into the boiler is regulated by hand by the engineer by means of cocks, and sometimes by spindle valves raised and lowered by a screw. Cocks appear to be the preferable expedient, as they are less liable to accident or derangement than screw valves, and in modern steam vessels they are generally employed.

Q. At what point of the boiler is the feed introduced?

A. The feed water is usually conducted from the feed cock to a point near the bottom of the boiler by means of an internal pipe, the object of this arrangement being to prevent the rising steam from being condensed by the entering water. By being introduced near the bottom of the boiler, the water comes into contact in the first place with the bottoms of the furnaces, and extracts heat from them which could not be extracted by water of a higher temperature, whereby a saving of fuel is accomplished. In some cases the feed water is introduced into a casing around the chimney, from whence it descends into the boiler. This plan appears to be an expedient one when the boiler is short of heating surface and more than a usual quantity of heat ascends the chimney; but in well-proportioned boilers a water-casing round the chimney is superfluous. When a water-casing is used with low pressures the boiler is generally fed by a head of water, the feed water being forced up into a small tank, from whence it descends into the boiler by the force of gravity, while the surplus runs to waste, as in the feeding apparatus of land engines. But in steam vessels this arrangement is now obsolete.

Q. Suppose that the engineer should shut off the feed water from the boilers while the engine was working, what would be the result?

A. The result would be to burst the feed pipes, except for a safety valve placed on the feed pipe between the engine and the boilers, which safety valve opens when any undue pressure comes upon the pipes, and allows the water to escape. There is, however, generally a cock on the suction side of the feed pump, which regulates the quantity of water drawn into the pump. But there must be cocks on the boilers also to determine into which boiler the water shall be chiefly discharged, and these cocks are sometimes all shut accidentally at the same time. Latterly feed cocks have been employed of such a construction that there is always a passage through them either to the boiler or to the overflow, or partly to both. With such cocks a safety valve on the feed pipe may be dispensed with, and yet the pipe will never be burst.

Q. Is there no expedient in use in steam vessels for enabling the position of the water level in the boiler to determine the quantity of feed water admitted?

A. In some steam vessels floats have been introduced to regulate the feed, but their action cannot be depended on in agitated water if applied after the common fashion. Floats would probably answer if placed in a cylinder which communicates with the water in the boiler by means of small holes; and a disc of metal might be attached to the end of a rod extending beneath the water level, so as to resist irregular movements from the motion of the ship at sea, which would otherwise impair the action of the apparatus.

Q. How is the proper level of the water in the boiler of a steam vessel maintained when the engine is stopped for some time, and the boiler is blowing off steam?

A. By means of a separate pump worked by a small separate engine called the Donkey engine. This pump, by the aid of suitable cocks, will pump from the sea into the boiler; from the sea upon deck, either to wash decks or to extinguish fire; and from the bilge overboard, through a suitable orifice in the side of the ship.

LOCOMOTIVE BOILERS.

Q. Will you recapitulate the general features of locomotive boilers?

A. Locomotive boilers consist of three portions—the barrel containing the tubes, the fire-box, and the smoke-box; of which the barrel, smoke-box, and external fire-box are always of iron or steel, but the internal fire-box is generally made of copper, though sometimes also it is made of iron or steel. The tubes are sometimes of iron, but generally of brass fixed in by ferrules. The whole of the plates of a locomotive boiler which are subjected to the pressure of steam should be of the best quality; and the copper should be coarse-grained, rather than rich or soft, and be perfectly free from irregularities of structure and lamination.

Q. What are the usual dimensions of the barrel?

A. The thickness of the plates composing the barrel of the boiler is generally about half an inch, and the plates should run in the direction of the circumference, so that the fibres of the iron may be in the direction of the greatest strain. The diameter of the barrel is commonly about 4 feet. The diameter of the rivets should be from ¹¹⁄₁₆ths to ¾ths of an inch, and the pitch of the rivets or distance between their centres should be from 1⅞ to 2 inches. It is better, however, to weld the butt joints or to use covering plates within and without for the six rows of rivets.

Q. How are the fire-boxes of locomotives constructed?

A. The space between the external and internal fire-boxes forms a water space, which must be stayed every 4½ or 5 inches by means of copper or iron stay bolts, screwed through the outer fire-box into the metal of the inner fire-box, and securely riveted within it: iron stay bolts are as durable as copper, and their superior tenacity gives them an advantage. Sometimes tubes have been employed as stays. The internal and external fire-boxes are joined together at the bottom, and round the fire door they are connected by means of a copper ring 1¼ inch thick and 2 inches broad—the inner fire-box being dished sufficiently outward at that point, and the outer fire-box sufficiently inwards, to enable a circle of rivets ¾ of an inch in diameter passing through the copper ring and the two thicknesses of iron to make a water-tight joint. The thickness of the plates composing the external fire-box is in general ½ an inch, and the thickness of the internal fire-box is in most cases ⁹⁄₁₆ths if copper, and from $\frac{7}{16}$ths to $\frac{1}{2}$ an inch if of iron. Rivet-heads are liable to be burnt away by the action of the fire; and when the fire-boxes are square each side should consist of a single plate, turned over at the edges with a radius of 3 inches, for the introduction of the rivets.

Q. Is there any provision for stiffening the crown of the furnace in a locomotive?

A. The roof of the internal fire-box requires to be stiffened with cross stay bars. The ends of these stay bars rest above the vertical sides of the fire-box; and to the stay bars thus extending across the crown, the crown is attached at intervals by means of stay bolts. There are projecting bosses upon the stay bars encircling the bolts at every point where a bolt goes through, but in the other parts they are kept clear of the fire-box crown, so as to permit the access of water to the metal; and, with the view of facilitating the ascent of the steam, the bottom of each stay bar should be sharpened away in those parts where it does not touch the boiler.

Q. Is any inconvenience experienced from the intense heat in a locomotive furnace?

A. The fire-bars in locomotives have always been a source of trouble, as from the intensity of the heat in the furnace they become so hot as to throw off a scale, and to bend under the weight of the fuel. The best alleviation of these evils lies in making the bars deep and thin: 4 or 5 inches deep by five-eighths of an inch thick on the upper side, and three-eighths of an inch on the under side, are found in practice to be good dimensions. In some locomotives a frame carrying a number of fire-bars was so made that it might be dropped suddenly by loosening a catch; but it was found that any such mechanism can rarely be long kept in working order, as the molten clinker, by running down between the frame and the boiler, will generally glue the frame into its place. It is, therefore, found preferable to fix the frame, and to lift up the bars by the dart used by the stoker, when any cause requires the fire to be withdrawn. The furnace bars of locomotives are always made of malleable iron, and indeed for every species of boiler malleable iron bars are to be preferred to bars of cast iron, as they are more durable, and may, if thin, be set closer together, whereby the small coal or coke is saved that would otherwise fall into the ash pit. The ash-box of locomotives is made of plate iron a quarter of an inch thick: it should not be less than 10 inches deep, and its bottom should be about 9 inches above the level of the rails. The chimney of a locomotive is made of plate iron one-eighth of an inch thick: it is usually of the same diameter as the cylinder, but is better smaller, and must not stand more than 14 feet high above the level of the rails.

Q. Are locomotive boilers provided with a steam chest?

A. The upper portion of the external fire-box is usually formed into a steam chest, and from this steam chest the steam is conducted away by an internal pipe to the cylinders; but in other cases an independent steam chest is set upon the barrel of the boiler, consisting of a plate iron cylinder, 20 inches in diameter, 2 feet high, and three-eighths of an inch thick, with a dome-shaped top, and with the seam welded and the edge turned over to form a flange of attachment to the boiler.

Q. Is any beneficial use made of the surplus steam of a locomotive?

A. To save the steam which is formed when the engine is stationary, a pipe is usually fitted to the boiler, which on a cock being turned conducts the steam into the water in the tender, whereby the feed water is heated, and less fuel is subsequently required. This method of disposing of the surplus steam may be adopted when the locomotive is descending inclines, or on any occasion where more steam is produced than the engine can consume.

Q. What means are provided to facilitate the inspection and cleaning of locomotive boilers?

A. The man-hole, or entrance into the boiler, consists of a circular or oval aperture, of about 15 inches diameter. In whatever situation this man-hole is placed, the surfaces of the ring encircling the hole, and of the internal part of the door or cover, should be accurately fitted together by scraping or grinding, so that they need only the interposition of a little red lead to make them quite tight when screwed together. Lead or canvas joints, if of any considerable thickness, will not long withstand the action of high-pressure steam; and the whole of the joints about a locomotive should be such that they require nothing more than a little paint or putty, or a ring of wire gauze smeared with white or red lead, to make them perfectly tight. There must be a mud-hole opposite the edge of each water space, to enable the boiler to be easily cleaned out, and these holes are most safely closed by doors put on from the inside. A cock for emptying the boiler is usually fixed at the bottom of the fire-box, and it should be so placed as to be accessible when the engine is at work, in order that the engine-driver may blow-off some water if necessary; but it must not be in such a position as to send the water blown off among the machinery, as it might carry sand or grit into the bearings, to their manifest injury.

Q. Will you state the dimensions of the tube plate and the means of securing the tubes in it?

A. The tube plates are generally made from three-fourths to seven-eighths of an inch thick, as when the plate is thick the holes will not be so liable to change their figure during the process of ferruling the tubes. The distance between the tubes should never be made less than three-fourths of an inch, and the holes should be slightly tapered so as to enable the tubes to hold the tube plates together. The tubes are usually secured in the tube plates by means of taper ferrules driven into the ends of the tubes. But sometimes ferrules are dispensed with. The ferrules are for the most part made of steel at the fire-box end, and of wrought iron at the smoke-box end, though ferrules of malleable cast iron have in some cases been used with advantage. Malleable cast iron ferrules are almost as easily expanded when hammered cold upon a mandril as the common wrought iron ones are at a working heat Spring steel, rolled with a feather edge, to facilitate its conversion into ferrules, is supplied by some of the steel-makers of Sheffield, and it appears expedient to make use of steel thus prepared when steel ferrules are employed. In cases where ferrules are not employed, it may be advisable to set out the tube behind the tube plate by means of an expanding mandril. There are various forms of this instrument; but the form now in most general use is that known as Dudgeon's, in which three small rollers are set out by a tapered central drift. These rollers are rotated within the tube.

Q. Will you explain the means that are adopted to regulate the admission of steam to the cylinders?

A. In locomotives the admission of the steam from the boiler to the cylinders is regulated by a valve called the regulator, which is generally placed immediately above the internal fire-box, and is connected with two copper pipes, one conducting steam from the highest point of the dome down to it, and the other conducting the steam that has passed through it along the boiler to the upper part of the smoke-box. Regulators may be divided into two sorts, viz., those with sliding valves and steam ports, and those with conical valves and seats, of which the latter kind are the best. The former kind have, for the most part, consisted of a circular valve and face with radial apertures, the valve resembling the outstretched wings of a butterfly, and being made to revolve on its central pivot by connecting links between its outer edges, or by its central spindle. In some of Stephenson's engines the regulator consists of a slide valve covering a port on the top of the valve chests. A rod passes from this valve through the smoke-box below the boiler, and by means of a lever parallel to the starting lever is brought up to the engineer's reach. Cocks were at first used as regulators, but were given up, as they were found liable to stick fast. A gridiron slide valve has been used by Stephenson, which consists of a perforated square plate moving upon a face with an equal number of holes. This plan of a valve gives, with a small movement, a large area of opening. The best regulator is probably a valve of the equilibrium description, such as is used in the Cornish engine. There is no friction in such a regulator, and it can be opened or shut with a small amount of force. Such valves are now frequently employed for regulators in locomotives.

TORPEDO-BOAT BOILERS.

Q. What kind of boilers are employed for torpedo-boats and other light vessels for which a high rate of speed is required?

A. The boilers of such boats are usually of the locomotive type. But as the engines are condensing engines, there can be no blast-pipe in the chimney for maintaining a strong draught. The stoke-hole is therefore made close and air is forced into it by a fan, by which means an action resembling that of a locomotive boiler is obtained.

Q. Is the structure of such boilers in all respects the same as that of a locomotive boiler?

A. There are some slight differences which it will be proper to specify. One is that there is a brick bridge intervening between the end of the bars and the beginning of the tubes. Another is that increased steam room is got by making the part of the shell over the fire-box flat, and by staying it by bolts to the top of the fire-box.

Q. What is the object of having this increased steam room?

A. To diminish priming.

Q. And why should these boilers prime more than locomotives?

A. Because, the engines being compound, the steam is taken away at more distant intervals.

Q. What other effects have been observed?

A. There has been much trouble from the tubes leaking at the ends, and when the steam was let down the tubes have been found to be slack in the holes, and the holes to be sometimes oval.

Q. To what do you attribute these results?

A. To the unequal expansion of the tubes and the shell. Where these inconveniences have been experienced, the tubes have been of brass and the fire-box of copper, and these parts have been so connected as to constitute a continuous piece. As the copper and brass expanded more than the iron shell, and as the free expansion of the tubes was thus prevented, some of them, in the effort to expand, were bent so much as to make the holes oval, while all were started at the ends.

Q. How is this to be prevented?

A. It was cured in the cases where it occurred by using an iron fire-box and iron tubes, which expanded less. But a better remedy would have been to corrugate the shell, which would have allowed the brass tubes and copper fire-box to expand without injury.

Q. How would this effect have been produced?

A. In the case of a simple cylindrical shell the effect of the greater expansion of the tubes and fire-box than of the shell will be either to strain the shell by extension or to crumple the tubes. But by corrugating the shell its longitudinal extension will be permitted without throwing much end strain upon the tubes.

CHAPTER VI.

CONSTRUCTIVE DETAILS OF ENGINES.

PUMPING ENGINES.

Q. Will you explain the course of procedure in the erection of a pumping engine, such as Boulton and Watt introduced into Cornwall?

A. The best instructions on this subject are those of Mr. Watt himself, which are as follows:—Having fixed on the proper situation of the pump in the pit, from its centre measure out the distance to the centre of the cylinder, from which set off all the other dimensions of the house, including the thickness of the walls, and dig out the whole of the included ground to the depth of the bottom of the cellar, so that the bottom of the cylinder may stand on a level with the natural ground of the place, or lower if convenient, for the less the height of the house above the ground, the firmer it will be. The foundations of the walls must be laid at least two feet lower than the bottom of the cellar, unless the foundation be firm rock; and care must be taken to leave a small drain into the pit quite through the lowest part of the foundation of the lever wall, to let off any water that may be spilt in the engine house, or may naturally come into the cellar. If the foundation at that depth does not prove good, you must either go down to a better, if in your reach, or make it good by a platform of wood or piles, or both.

Q. These directions refer to the foundations?

A. Yes; but I will now proceed to the other parts. Within the house low walls must be built to carry the cylinder beams, so as to leave sufficient room to come at the holding down bolts, and the ends of these beams must also be lodged in the wall. The lever wall must be built in the firmest manner, and run solid, course by course, with thin lime mortar, care being taken that the lime has not been long slaked. If the house be built of stone, let the stones be large and long, and let many headers be laid through the wall; it should also be a rule that every stone be laid on the broadest bed it has, and never set on its edge. A course or two above the lintel of the door that leads to the condenser, build into the wall two parallel, flat, thin bars of iron equally distant from each other, and from the outside and inside of the wall, and reaching the whole breadth of the lever wall. About a foot higher in the wall, lay at every four feet of the breadth of the front other bars of the same kind at right angles to the former course, and reaching quite through the thickness of the wall; and at each front corner lay a long bar in the middle of the side walls, and reaching quite through the front wall; if these bars are 10 feet or 12 feet long it will be sufficient. When the house is built up nearly to the bottom of the opening under the great beam, another double course of bars is to be built in as has been directed. At the level of the upper cylinder beams, holes must be left in the walls for their ends with room to move them laterally, so that the cylinder may be got in; and smaller holes must be left quite through the walls for the introduction of iron bars, which being firmly fastened to the cylinder beams at one end, and screwed at the other or outer end, will serve, by their going through both the front and back walls, to bind the house more firmly together. The spring beams or iron bars fastened to them must reach quite through the back wall, and be keyed or screwed up tight; and they must be firmly fastened to the lever wall on each side, either by iron bars, firm pieces of wood, or long, strong stones reaching far back into the wall. They must also be bedded solidly, and the residue of the opening must be built up in the firmest manner.

Q. If there be a deficiency of water for the purpose of condensation, what course should be pursued?

A. If there be no water in the neighbourhood that can be employed for the purpose of condensation, it will be necessary to make a pond, dug in the earth, for the reception of the water delivered by the air pump, to the end that it may be cooled and used again for the engine. The pond may be three or four feet deep, and lined with turf, puddled, or otherwise made water-tight. Throwing up the water into the air in the form of a jet to cool it has been found detrimental, as the water is then charged with air, which vitiates the vacuum.

Q. How is the piston of a pumping engine packed?

A. To pack the piston, take sixty common-sized white or untarred rope-yarns, and with them plait a gasket or flat rope as close and firm as possible, tapering for eighteen inches at each end, and long enough to go round the piston, and overlapped for that length; coil this rope the thin way as hard as possible, and beat it with a sledge hammer until its breadth answers the place; put it in and beat it down with a wooden drift and a hand mallet, pour some melted tallow all around, then pack in a layer of white oakum half an inch thick, so that the whole packing may have the depth of five to six inches, depending on the size of the engine; finally, screw down the junk ring. The packing should be beat solid, but not too hard, otherwise it will create so great a friction as to prevent the easy going of the engine. Abundance of tallow should be allowed, especially at first; the quantity required will be less as the cylinder grows smooth. In some of the more modern pumping engines the piston is provided with metallic packing, consisting for the most part of a single ring with a tongue piece to break the joint, and packed behind with hemp. The upper edge of the metallic ring is sharpened away from the inside, so as to permit more conveniently the application of hemp packing behind it; and the junk ring is made much the same as if no metallic packing were employed.

Q. Will you explain the mode of putting the engine into operation?

A. To set the engine going, the steam must be raised until the pressure in the steam pipe is at least equal to three pounds on the square inch; and when the cylinder jacket is fully warmed, and steam issues freely from the jacket cock, open all the valves or regulators; the steam will then forcibly blow out the air or water contained in the eduction pipe, and to get rid of the air in the cylinder, shut the steam valve after having blown through the engine for a few minutes. The cold water round the condenser will condense some of the steam contained in the eduction pipe, and its place will be supplied by some of the air from the cylinder. The steam valve must again be opened to blow out that air, and the operation is to be repeated until the air is all drawn out of the cylinder. When that is the case shut all the valves, and observe if the vacuum gauge shows a vacuum in the condenser. When there is a vacuum equivalent to three inches of mercury, open the injection a very little, and shut it again immediately; and if this produces any considerable vacuum, open the exhausting valve a very little way, and the injection at the same time. If the engine does not now commence its motion, it must be blown through again until it moves. If the engine be lightly loaded, or if there be no water in the pumps, the throttle valve must be kept nearly closed, and the top and exhaustion regulators must be opened only a very little way, else the engine will make its stroke with violence, and perhaps do mischief. If there is much unbalanced weight on the pump end, the plug which opens the steam valve must be so regulated that the valve will only be opened very slightly; and if after a few strokes it is found that the engine goes out too slowly, the valve may be then so adjusted as to open wider. The engine should always be made to work full stroke, that is, until the catch pins are made to come within half an inch of the springs at each end, and the piston should stand high enough in the cylinder, when the engine is at rest, to spill over into the perpendicular steam pipe any water which may be condensed above it; for if water remain upon the piston, it will increase the consumption of steam. When the engine is to be stopped, shut the injection valve and secure it, and adjust the tappets so as to prevent the exhausting valve from opening and to allow the steam valve to open and remain open, otherwise a partial vacuum may arise in the cylinder, and it may be filled with water from the injection or from leaks. A single-acting engine, when it is in good order, ought to be capable of going as slow as one stroke in ten minutes, and as fast as ten strokes in one minute; and if it does not fulfil these conditions, there is some fault which should be ascertained and remedied.

Q. Your explanation has reference to the pumping engine as introduced into Cornwall by Watt: have any modifications been since made upon it?

A. In the modern Cornish engines the steam is used very expansively, and a high pressure of steam is employed. In some cases a double cylinder engine on Hornblower's plan is used, in which the steam, after having given motion to a small piston on the principle of a high-pressure engine, passes into a larger cylinder, where it operates on the principle of a condensing engine; but, as already explained, there is no superior effect gained by the use of two cylinders, and there is greater complexity in the apparatus. Instead of the lever walls, cast iron columns are now frequently used for supporting the main beam in pumping engines, and in engines made in Cornwall the cylinder end of the main beam is generally made longer than the pump end, so as to enable the cylinder to have a long stroke and the piston to move quickly, without communicating such a velocity to the pump buckets as will make them work with such a shock as to wear themselves out quickly. A high pressure of steam, too, can be employed where the stroke is long, without involving the necessity of making the working parts of such large dimensions as would otherwise be necessary; for the strength of the parts of a single-acting engine will require to be much the same, whatever the length of the stroke may be.

Q. What kind of pump is mostly used in draining deep mines?

A. The pump now universally preferred is the plunger pump, which admits of being packed or tightened while the engine is at work; but the lowest lift of a mine is generally supplied with a pump on the suction principle, both with the view of enabling the lowest pipe to be lengthened, so as to follow the water with facility as the shaft is sunk deeper, and to obviate the inconvenience of the valves of the pump being rendered inaccessible by any flooding in the mine. The pump valves of deep mines are a perpetual source of expense and trouble, as from the pressure of water upon them it is difficult to prevent them from closing with violence; and many expedients have been contrived to mitigate the evil, of which the valve known as Harvey and West's valve has, perhaps, gained the widest acceptation.

Q. Will you describe Harvey and West's pump valve?

A. This valve is a compromise between the equilibrium valve, of the kind employed for admitting the steam to and from the cylinder in single-acting engines, and the common spindle valve; and to comprehend its action, it is necessary that the action of the equilibrium valve should first be understood. This valve consists substantially of a cylinder open at both ends, and capable of sliding upon a stationary piston fixed upon a rod of the length of the cylinder, which proceeds from the centre of the orifice the valve is intended to close. It is clear that, when the cylinder is pressed down until its edge rests upon the bottom of the box containing it, the orifice of the pipe must be closed, as the steam can neither escape past the edge of the cylinder nor between the cylinder and the piston; and it is equally clear, that as the pressure upon the cylinder is equal all around it, and the whole of the downward pressure is sustained by the stationary piston, the cylinder can be raised or lowered without any further exertion of force than is necessary to overcome the friction of the piston and of the rod by which the cylinder is raised. Instead of the rubbing surface of a piston, however, a conical valve face between the cylinder and piston is employed, which is tight only when the cylinder is in its lowest position ; and there is a similar face between the edge of the cylinder and the bottom of the box in which it is placed. The moving part of the valve, too, instead of being a perfect cylinder, is bulged outwards in the middle, so as to permit the steam to escape past the stationary piston when the cylindrical part of the valve is raised. It is clear, that if such a valve were applied to a pump, no pressure of water within the pump would suffice to open it, neither would any pressure of water above the valve cause it to shut with violence ; and if an equilibrium valve, therefore, be used as a pump valve at all, it must be opened and shut by mechanical means. In Harvey and West's valve, however, the equilibrium principle is only partially adopted; the lower face is considerably larger in diameter than the upper face, and the difference constitutes an annulus of pressure, which will cause the valve to open or shut with the same force as a spindle valve of the area of the annulus. To deaden the shock still more effectually, the lower face of the valve is made to strike upon end wood driven into an annular recess in the valve seat or pump bucket; and valves thus constructed work with very little noise or tremor. But it is found in practice that the use of Harvey and West's valve, or any contrivance of a similar kind, adds materially to the load upon the pump, especially in low lifts, where the addition of weight to the valve makes a material addition to the total resistance which the engine has to overcome. Instead of end wood driven into a recess for the valve to strike upon, a mixture of tin and lead cast in a recess is now frequently used, and is found to be preferable to the wood.

Q. Is there any other kind of pump valve which is free from the shocks incidental to the working of common valves ?

A. In some cases indiarubber valves are used for pumps, with the effect of materially mitigating the shock ; but they require frequent renewal, and are of inferior eligibility in their action to the slide valve, which might in many cases be applied to pumps without inconvenience.

Q. Will not the use of an air vessel diminish the shock upon the valves ?

A. No doubt that will be so ; and all important pumps are furnished with air vessels, not merely upon the forcing, but upon the suction side, as the momentum of the column of water entering through the suction pipe will not only otherwise occasion a shock, but the regurgitation will, to some extent, hinder the entrance of the water. It is consequently desirable to make the suction pipe as short as possible, and also to introduce air vessels both on the suction and forcing sides. In the bucket and plunger pump, the water is drawn only during the ascent of the bucket, but forced in both the ascent and descent.

Q. What is the bucket and plunger pump?

A. It is a pump made with a bucket having a valve in it like a common sucking pump, but with the pump rod enlarged so much as to constitute a plunger. The area of the plunger is usually made half the area of the bucket, and the plunger passes through a water-tight stuffing-box in the usual manner. It follows from this construction that when the bucket descends the water passes through the valve in the bucket, to occupy the upper part of the barrel. But the space there existing is reduced to one-half by reason of the intrusion of the plunger, and as there is not room for the whole of the water above the bucket which was previously beneath it, and as the water has to go somewhere, it opens the delivery valve against the pressure of the head, and half the content of the barrel thus escapes. When the bucket ascends the water lying above it is expelled. But the quantity there remaining is only half that which the pump took in. In the bucket and plunger pump, therefore, the sucking action is precisely the same as that of a common single-acting or sucking pump. But the forcing action is the same as that of a double-acting force pump, and by its employment a more uniform or more continuous propulsion of the water is obtained. This kind of pump was invented by Jacob Perkins, but was first employed by Mr. David Thomson in the Richmond Waterworks, about 1842, since which time its employment has been greatly extended.

Q. What is the most approved species of engine used in waterworks at the present time?

A. The beam engine seems to be in greatest favour, and in some cases the double cylinder type is employed, and in other cases the single cylinder engine. Both systems were introduced into the New River Waterworks side by side, the double cylinder engines constructed by Mr. David Thomson, and the single cylinder engines by Boulton and Watt. A very excellent performance was obtained in both cases; but, on the whole, the advantage seemed to lie with the single cylinder engines. At all events, the double cylinder system showed no superiority of performance, and the complication was somewhat greater. The whole of the engines were double-acting rotative engines with cranks and fly wheels, and the pumps were of the bucket and plunger type.

Q. Then single-acting engines working at a low rate of speed, and with the valves moved by hand-gear, are not now in much favour for waterworks?

A. No, they are not; and even in the case of mines, where the system is more permissible, it appears probable that rotative engines, working at a high speed and with the pumps geared down, would, on the whole, be preferable to the single-acting arrangement. The fact is, the single-acting engine is the survival of a more primitive state, which must now be superseded by more compendious contrivances. The Cornish engines, though often rudely manufactured, are very expensive in production, as a large engine does but little work; whereas, by employing a smaller engine, moving with a high speed, the dimensions may be so far diminished that the most refined machinery can be obtained at less than the present cost. Cornish engines of a high quality made by Messrs. Harvey, of Hayle, and others, have been introduced into some of the London waterworks and elsewhere with excellent results. Nevertheless, the principle is now obsolete and should be abandoned.

Q. Are not the Cornish engines more economical in fuel than other engines?

A. It is a mistake to suppose that there is any peculiar virtue in the existing form of Cornish engine to make it economical in fuel, or that a less lethargic engine would necessarily be less efficient. The large duty of the engines in Cornwall is traceable to the large employment of the principle of expansion, and to a few other causes which may be made of quite as decisive efficacy in smaller engines working with a quicker speed; and there is therefore no argument in the performance of the present engines against the proposed substitution.

Q. Will you give an example of a double cylinder engine of modern type such as is used in waterworks for the supply of towns?

A. I will select for this purpose the engines erected in 1859, from the designs of Mr. Hawksley, for supplying water to Altona, a town in Holstein, situated near the mouth of the Elbe. There are two engines, and they have been erected beside the river at the foot of a hill 300 feet high, on the top of which the filter beds and reservoirs have been placed. Steam is supplied for the engines by four Cornish boilers, and engines and boilers were constructed

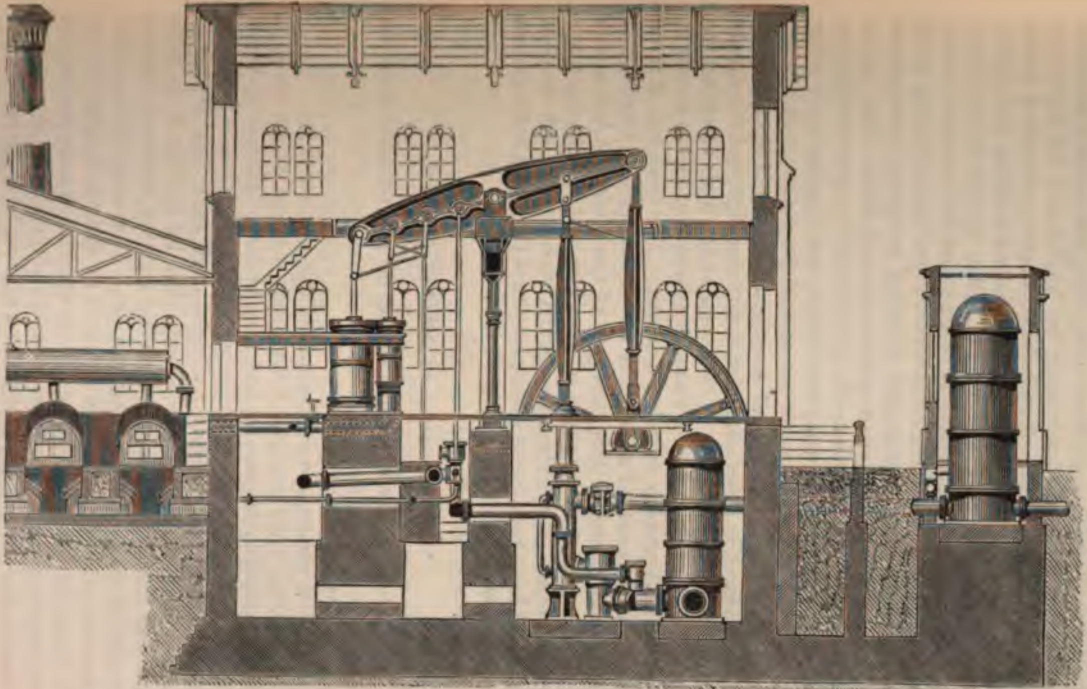


Fig. 88.—Double Cylinder Pumping Engines of the Altona Waterworks, erected under the direction of Mr. Hawksley, 1859.

by Messrs. Hawthorn, of Newcastle. The low-pressure cylinders are each 35 inches diameter and 7 feet stroke, and the high-pressure cylinders are each of 20 inches diameter and 5 feet 3 inches stroke. The pressure of steam in the boilers is 28 lbs. per square inch, and it may be cut off at ⅝ths, ¾ths, or ⅞ths of the small cylinder. The ultimate pressure of the steam in the large cylinder is about 3½ lbs. Each engine is separate, and has its own fly wheel 20 feet 8 inches diameter and weighing 16 tons. Each engine makes about 15 revolutions per minute and exerts 62·45 actual horses-power, with a consumption of 3·63 lbs. of coal per actual horse-power per hour when using two boilers, and 3·34 lbs. when using three. The pumps, being placed at half the radius of the beam, have a stroke of 3½ feet and a cubical capacity of 8⅜ cubic feet. The air vessel is 5 feet diameter and 18 feet high, and the supply of air is maintained within it by means of small air valves on the suction side of the pumps. The suction pipe is 21 inches diameter, and the delivery pipe 15 inches diameter. The total cost of these waterworks was about 80,000*l.*, of which the engines, boilers, and fittings cost 7,000*l.*, or less than $\frac{1}{10}$th of the whole. A better performance than the foregoing has been obtained in many pumping engines of the single cylinder type, and such engines are simpler. It would have been better if the pressure of the steam in the Altona engines had been twice as great as it is.

VARIOUS FORMS OF MARINE ENGINES.

Q. What species of paddle engine do you consider to be the best?

A. The oscillating engine.

Q. Will you explain the grounds of that preference?

A. The engine occupies little space, consists of few parts, is easily accessible for repairs, and may be both light and strong at the same time. In the case of large engines the crank in the intermediate shaft was formerly a disadvantage, as it was difficult to obtain such a forging quite sound. But by forging it in three cranked flat bars, which were then laid together and welded into a square shaft, a sound forging was got. The cranked bars were rounded a little on the sides which were welded, to allow the scoriæ to escape during that operation. It is important in so large a forging not to let the fire be too fierce, else the surface of the iron will be *burnt before* the heart is brought to a welding heat. In some cases in oscillating engines the air pump has been wrought by an eccentric, and that may at any time be done where doubt of obtaining a sound intermediate shaft is entertained. But the precaution must be taken to make the eccentric very wide, so as to distribute the pressure over a large surface, else the bearing will be apt to heat, and an eccentric is more clumsy than a crank. A crank obtained by bending the shaft will do very well. But there is no longer any difficulty in making cranks of any desired form perfectly sound.

Q. Have not objections been brought against the oscillating engine?

A. In common with every other improvement, the oscillating engine, at the time of its introduction, encountered much opposition. The cylinder, it was said, would become oval, the trunnion bearings would be liable to heat and the trunnion joints to leak, the strain upon the trunnions would be apt to bend in or bend out the sides of the cylinder; and the circumstance of the cylinder being fixed across its centre, while the shaft requires to accommodate itself to the working of the ship, might, it was thought, be the occasion of such a strain upon the trunnions as would either break them or bend the piston rod. It is a sufficient reply to these objections to say that they are all hypothetical, and that none of them in practice have been found to exist—to such an extent, at least, as to occasion any inconvenience. But it is not difficult to show that they are altogether unsubstantial, even without a recourse to the disproofs afforded by experience.

Q. Is there not a liability in the cylinder to become oval from the strain thrown on it by the piston?

A. There is, no doubt, a tendency in oscillating engines for the cylinder and the stuffing-box to become oval. But after a number of years' wear it is found that the amount of ellipticity is less than that which is found to exist in the cylinders of side lever engines after a similar trial. The resistance opposed by friction to the oscillation of the cylinder is so small, that a man is capable of moving a large cylinder with one hand; whereas in the side lever engine, if the parallel motion be in the least untrue, which is, at some time or other, an almost inevitable condition, the piston is pushed with great force against the side of the cylinder, whereby a large amount of wear and friction is occasioned. The trunnion bearings, instead of being liable to heat like other journals, are kept down to the temperature of the steam by the flow of steam passing through them; and the trunnion packings are not liable to leak when the packings, before being introduced, are squeezed in a cylindrical mould.

Q. Might not the eduction trunnions be immersed in water?

A. In some cases a hollow, or lantern brass, about one-third or one-fourth the length of the packing space, and supplied with steam or water by a pipe, has been introduced in the middle of the packing, so that if there were any leakage through the trunnion, it would be a leakage of steam or water, which would not vitiate the vacuum. But in ordinary cases this device is not necessary, and it is not commonly employed. It is clear that there can be no buckling of the sides of the cylinder by the strain upon the trunnions, if the cylinder be made strong enough, and in cylinders of the ordinary thickness such an action has never been experienced. Nor is it the fact, that the intermediate shaft of steam vessels, to which part alone the motion is communicated by the engine, requires to adapt itself to the altering forms of the vessel, as the engine and intermediate shaft are rigidly connected, although the paddle shafts require to be capable of such an adaptation. Even if this objection existed, however, it could easily be met by making the crank pin of the ball and socket fashion, which would permit the position of the intermediate shaft, relatively with that of the cylinder, to be slightly changed, without throwing an undue strain upon any of the working parts.

Q. Is the trunk engine inferior to the oscillating?

A. A very elegant and efficient arrangement of trunk engine suitable for paddle vessels has sometimes been employed by Messrs. Rennie, of which all the parts resemble those of Penn's oscillating engine except that the cylinders are stationary instead of being movable; and a round trunk or pipe set upon the piston, and moving steam-tight through the cylinder cover, enables the connecting rod which is fixed to the piston to vibrate within it to the requisite extent. But the vice of all trunk engines is that they are necessarily more wasteful of steam, as the large mass of metal entering into the composition of the trunk, moving as it does alternately into the atmosphere and the steam, must cool and condense a part of the steam. The radiation of heat from the interior of the trunk will have the same operation, though the loss from this cause might probably be reduced by lining the trunk with wood.

Q. What species of screw engine do you consider the best?

A. If the engine has to be kept below the water line I am inclined to give the preference to the variety of the horizontal steeple engine, first used in H.M.S. 'Amphion,' and of which a representation has already been given in fig. 57, which represents one of the engines of the French war steamer 'Friedland.' In this engine the cylinders lie on their sides, and they are placed near the side of the vessel with their mouths pointing towards the keel. From each cylinder two long piston rods proceed across the vessel to a cross head working in guides; and from this cross head a connecting rod returns back to the centre of the vessel and gives motion to the crank. The piston rods are placed in the piston diagonally, and one of them passes above the crank shaft, and the other below the crank shaft. The cross head lies in the same horizontal plane as the centre of the cylinder, and a lug projects upwards from the cross head to engage one piston rod, and downwards from the cross head to engage the other piston rod. The air pump is double-acting, and its piston or bucket has the same stroke as the piston of the engine. The air-pump bucket derives its motion from an arm on the cross head, and a similar arm is usually employed in engines of this class to work the feed and bilge pumps. For mercantile purposes, where the engine has not to be kept below the water line, the inverted engine is perhaps the form to be preferred.

Q. Is not inconvenience experienced in direct-acting screw engines from the great velocity of their motion?

A. Not if they are properly constructed; but they require to be much stronger, to be fitted with more care, and to have the bearing surfaces much larger than is necessary in engines moving slowly. The momentum of the reciprocating parts should also be balanced by a weight applied to the crank. A very convenient arrangement for obtaining surface is to form the crank of each engine of two iron or steel discs cast with heavy sides, the excess of weight upon the heavy sides being nearly equal to that of the piston and its connections. When the piston is travelling in one direction, the weights are travelling in the opposite; and the momentum of the piston and its attachments, which is arrested at each reciprocation, is just balanced by the equal and opposite momentum of the weights. One advantage of the horizontal engine is, that a single engine may be employed in small vessels, whereby greater simplicity of the machinery and greater economy of fuel will be obtained, since there will be less radiating surface in one cylinder than in two. There will also be no liability with one engine of the parts of one being broken by the other.

CYLINDERS, PISTONS, AND VALVES.

Q. Is it a beneficial practice to make cylinders with steam jackets?

A. In Cornwall, where great attention is paid to economy of fuel, all the engines are made with steam jackets, and in some cases a flue has been carried spirally round the cylinder, for keeping the steam hot. But smoke is not so effective a heater as steam. Mr. Watt in his early practice discarded the steam jacket for a time, but resumed it again, as he found its discontinuance occasioned a perceptible waste of fuel; and in modern engines it has been found that where a jacket is used about 10 per cent. less coal is consumed than where the use of a jacket is rejected. The cause of this at one time was not of very easy perception, for the jacket exposes a larger radiating surface for the escape of the heat than the cylinder; but since Joule's researches the result is known to be consequent on the superior economy of high temperatures in the production of power, and the heat of the jacket keeps up the volume of the expanding steam within the cylinder in engines working expansively. The exterior of the cylinder, or jacket, should be covered with several plies of felt, and then be cased in timber, which must be in narrow planks, the boards being first dried in a stove, and then bound round the cylinder with hoops, like the staves of a cask. In many engines the steam is let into chambers formed in the cylinder cover and cylinder bottom, for the further economisation of the heat, and the cylinder stuffing-box is made very deep, and a lantern or hollow brass is sometimes introduced into the centre of the packing, into which brass the steam gains admission by a pipe provided for the purpose; so that in the event of the packing becoming leaky, it will be steam that will be leaked into the cylinder instead of air, which, being incondensable, would impair the efficiency of the engine. A lantern brass, of a similar kind, has sometimes been introduced into the stuffing-boxes of oscillating engines, but its use there has been to receive the lateral pressure of the piston rod, and thus take any strain off the packing.

Q. Will you explain the proper course to pursue in the production of cylinders?

A. In all engines the valve casing, if made in a separate piece from the cylinder, should be attached by means of a metallic joint, as such a barbarism as a rust joint in such situations is no longer permissible. In the case of large engines with valve casings suitable for long D slides, an expansion joint in the valve casing was inserted, otherwise the steam, by gaining admission to the valve casing before it could enter the cylinder, expanded the casing while the cylinder remained unaltered in its dimensions, and the joints were damaged, and in some cases the cylinder was cracked by the great strain thus introduced. Long D valves, however, have now gone out of use. The chest of the blow-through valve is very commonly cast upon the valve casing; and in engines where the cylinders are stationary this is the most convenient practice. All engines, where the valve is not of such a construction as to leave the face when a pressure exceeding that of the steam is created within the cylinder by priming or otherwise, should be provided with an escape valve at each end to let out the water, and such valve should be so constructed that the water cannot fly out with violence over the attendants ; but it should be conducted away by a suitable pipe to a place where its discharge can occasion no inconvenience. The stuffing-boxes of all engines which cannot be stopped frequently to be repacked should be made very deep : metallic packing in the stuffing-box has been used in some engines, consisting in most instances of one or more rings, cut, sprung, and slipped upon the piston rod before the cross head is put on, and packed with hemp behind. This species of packing answers very well when the piston rod is free from scratches, and it accomplishes a material saving of tallow. In some cases a piece of sheet brass, packed behind with hemp, has been introduced with good effect, a flange being turned over on the under edge of the brass to prevent it from slipping up or down with the motion of the rod. The sheet brass speedily puts an excellent polish upon the rod, and such a packing is more easily kept, and requires less tallow than where hemp alone is employed. In side lever marine engines the attachments of the cylinder to the diagonal stay were generally made of too small an area, and the flanges were made too thick. A very thick flange cast on any part of a cylinder endangers the soundness of the cylinder, by inducing an unequal contraction of the metal in cooling.

Q. In what way are the steam jackets of engines usually formed?

A. The general practice is to cast the cylinder of strong, tough metal, and to cast a liner or bush a little smaller than the cylinder of the hardest metal that can be got. The cylinder has a ledge projecting inward about ½ an inch and a few inches deep near the mouth, and an annular recess suitable for the reception of a flange projecting a few inches inward at the bottom. The bush is formed like an open pipe with a ring a few inches deep projecting outwards near the top and a flange projecting inward a few inches, round the bottom. The cylinder mouth is bored out, as also the annular recess at the bottom. The corresponding parts of the bush are accurately turned, and the liner, being dropped into the cylinder, is securely bolted thereto by the bottom internal flange, and also fits accurately round the mouth by reason of the projecting ledges left at that part. A small portion of this fitting surface at the mouth is widened out so as to constitute a sort of stuffing-box, into which a copper wire is spirally caulked until several turns of the wire have been thus forced in, and finally a flat iron ring is screwed down upon the end of the liner to keep the copper wire in. A yarn of asbestos is sometimes used instead of the copper wire, or in addition thereto, the purpose of both arrangements being to form a slipping joint at this point, so that, if the cylinder and the liner should expand unequally, a small amount of motion here will avert any injurious strain upon the fitted parts. It is only a small portion at the ends of the liner that has to be turned, and a small portion at the ends of the cylinder that has to be bored. The intervening surfaces, being at a lower level, are left rough, and the space lying between the rough surfaces constitutes the jacket. Of course the bush is accurately bored out in the interior, as into it the piston is fitted.

Q. Can this bush, once it has been placed within the cylinder, be afterwards removed?

A. It may. By undoing the bolts which tie the internal flange of the bush to the cylinder the bush may be drawn out. In some cases these bolts, being countersunk to clear the piston, have been formed with heads like screw nails. But when thus formed it is difficult to screw the joint well up, and also difficult to take out the bolts again. It is better to form the bolts with hexagon heads and to recess them into the thickness of the flange, so that they may be turned by a box key. It is also better to form these bolts of gun-metal, as such bolts do not get rusted in.

Q. Which is the most eligible species of piston?

A. For large engines, pistons with a metallic packing, consisting of a single ring, with the ends morticed into one another, and a piece of metal let in flush over the joint and riveted to one end of the ring, appears to be the best species of piston. It will be expedient to make the vertical joints of the ends of the ring run a little obliquely, so as to prevent the joint from forming a ridge in the cylinder. For small pistons two rings may be employed, made somewhat eccentric internally by giving a greater thickness of metal in the centre of the ring. These rings must be set one above the other in the cylinder, and the joints, which are oblique, must be set at right angles with one another, so as to prevent leakage, and also to obviate any disposition of the rings, in their expansion, to wear the cylinder oval. The rings must first be turned a little larger than the diameter of the cylinder, and a piece is then to be cut out, so that when the ends are brought together the ring will just enter within the cylinder. The ring, while retained in a state of compression, is then to be put in the lathe and turned very truly, and finally it is to be hammered on the inside with the small end of the hammer, to expand the metal, and thus increase the elasticity.

Q. The rings should be carefully fitted to one another laterally?

A. The rings are to be fitted laterally to the piston, and to one another, by scraping—a steady pin being fixed upon the flange of the piston, and fitting into a corresponding hole in the lower ring, to keep the lower ring from turning round; and a similar pin being fixed into the top edge of the lower ring to prevent the upper ring from turning round. But the holes into which these pins fit must be made oblong, to enable the rings to press outward as the rubbing surfaces wear. In most cases it will be expedient to press the packing rings out with springs where they are not packed behind with hemp, and the springs should be made very strong, as the prevailing fault of springs is their weakness. Sometimes short, bent springs, set round at regular intervals between the packing rings and body of the piston, are employed, the centre of each spring being secured by a steady pin or bolt screwed into the side of the piston; but it will not signify much what kind of springs is used, provided they have sufficient tension. When pistons are made of a single ring, or of a succession of single rings, the strength of each ring should be tested previously to its introduction into the piston, by means of a lever loaded by a heavy weight.

Q. How should the piston rod be secured to the piston?

A. The piston rod, where it fits a taper eye in the piston, should have a good deal of taper; for, if the taper be too small, the rod will be drawn through the hole, and the piston will be split asunder. Small grooves are sometimes turned out of the piston rod above and below the cutter hole, and hemp is introduced in order to make the piston eye tight. Many piston rods are fixed to the piston by means of a gib and cutter, but in some cases the upper portion of the rod within the eye is screwed, and it is fixed into the piston by means of an indented nut.

Q. Which is the most beneficial construction of slide valve?

A. The best construction of slide valve appears to be that which consists of a three-ported valve, to the back of which a ring is applied of an area equal to that of the exhaustion port, and which, by bearing steam-tight against the back of the valve, so that a vacuum may be maintained within the ring, puts the valve in equilibrium, so that it may be moved with an inconsiderable exercise of force. The back of the valve casing is put on like a door, and into it a ring is indented, which is kept tight against the back of the valve by means of screws. In locomotive engines the valve universally employed is the common three-ported valve.

Q. Then the equilibrating ring should be attached to the valve casing instead of to the valve itself?

A. It should; and that method of construction, first introduced by myself in 1857, and subsequently employed in the case of engines constructed under my direction by Messrs. Rennie, is now very generally adopted, and is to be preferred, as it enables the ring to be tightened against the back of the valve while the engine is at work. An example of this species of valve is given in fig. 89, where A A are the portions of the casing to which the steam has free access, and B B are the eduction outlets, C C are the cylind ports, D is the valve rod, E E are the door or cover of the val

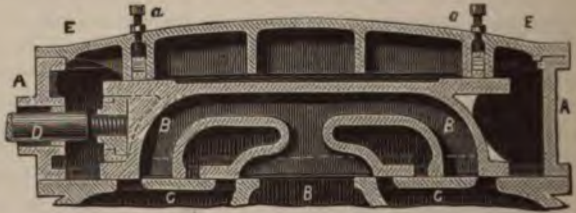


Fig. 89.—Balanced Gridiron Valve with interposed Springs.

casing, and *aa* are screws which press spiral springs, which press the indented ring down upon the valve. Springs are interposed between the ring and the points of the bolts, so that the valve may be enabled to leave its face, and thus let out the water should priming occur. This valve is what is termed a gridiron valve, by which is understood an arrangement whereby each cylinder port is split into two or more narrow ports, and the corresponding valve face is split into two or more narrow faces ; and these narrow ports being simultaneously opened and closed by their respective narrow faces, the necessary area of port is obtained with a small amount of travel in the valve. In modern engines of large size gridiron valves are usually employed ; and the equilibrium ring should in all cases be recessed into the door of the valve casing with interposed springs, which will enable the valve to leave the face should priming occur ; to which end the annulus which holds the ring should not itself come down as far as the back of the valve, but the ring should be made deep and projecting well beyond its containing annulus, so that the valve shall be enabled to leave the face when the springs are compressed. For direct-acting screw engines this species of valve is now extensively used.

Q. Will you describe the expedient by which the valve is moved?

A. The valve is moved by an eccentric; and formerly, in marine engines, whether paddle or screw, if moving at a slow rate of speed, the eccentric was generally loose upon the shaft, for the purpose of backing, and was furnished with a back balance and catches, so that it might stand either in the position for going ahead, or in that for going astern. The body of the eccentric was of cast iron, and was put on the shaft in two pieces. The halves were put together with rebated joints to keep them from separating laterally, and they were prevented from sliding out by round steel pins, each ground into both halves. Square keys would probably have been preferable to round pins in this arrangement, as the pins tended to wedge the jaws of the eccentric asunder. In some cases the halves of the eccentric were bolted together by means of flanges, which is, perhaps, the preferable practice.

Q. Are such eccentrics used in direct-acting screw engines?

A. No ; direct-acting screw engines are usually fitted with the link motion and two fixed eccentrics for each engine.

Q. Of what material is the eccentric hoop made?

A. The eccentric hoop in marine and land engines is generally of brass: it is expedient to cast an oil cup on the eccentric hoop, and, where practicable, a pan should be placed beneath the eccentric for the reception of the oil droppings. The eccentric catches of the kind formerly employed in marine engines sometimes broke off at the first bolt hole, and it is preferable, where loose eccentrics are used, to have a bolt in advance of the catch face, or to have a hoop encircling the shaft with the catches welded on it, the hoop itself being fixed by bolts or a key. This hoop may either be put on before the cranks in one piece or afterwards in two pieces.

AIR PUMP AND CONDENSER.

Q. What are the details of the air pump?

A. The air pump barrel and bucket and guards are made of brass in modern marine engines, and the valves are usually india-rubber discs working on grids. Air-pump rods of Muntz's metal or copper are much used. Iron rods covered with brass are generally wasted away where the bottom cone fits into the bucket eye, and if the casing be at all porous, the water will insinuate itself between the casing and the rod and eat away the iron. If iron rods covered with brass be used, the brass casing should come some distance into the bucket eye; the cutter should be of brass, and a brass washer should cover the under side of the eye, so as to defend the end of the rod from the salt water. Rods of Muntz's metal are probably on the whole to be preferred.

Q. What species of packing is used in air-pump buckets?

A. Metallic packing has in some instances been employed, but its success has not been such as to lead to its further adoption. The packing commonly employed is hemp, but sometimes wood. A deep, solid block of metal, however, without any packing, is often employed with a satisfactory result; but this block should have circular grooves cut round its edge to hold water. Where hemp packing is employed, the bucket should always be made with a junk ring, whereby the packing may be easily screwed down at any time. In slow moving engines the bucket valve is often made of brass, of the spindle or pot-lid kind, but butterfly valves are sometimes used. The foot and delivery valves in such engines are for the most part of the flap or hanging kind, and are placed outside of the pump. These valves all make a considerable noise in working.

Q. Where is the delivery valve usually situated?

A. Some delivery valve seats are bolted into the mouth of the air pump, whereby access to the pump bucket is rendered difficult; but more commonly the delivery valve is a flap valve exterior to the pump. If delivery valve seats be put in the mouth of the air pump at all, the best mode of fixing them appears to be that adopted by Messrs. Maudslay. The top of the pump barrel is made quite fair across, and upon this flat surface a plate containing the delivery valve is set, there being a small ledge all round to keep it steady. Between the bottom of the stuffing-box of the pump cover and the eye of the valve seat a short pipe extends, encircling the pump rod, its lower end checked into the eye of the valve seat, and its upper end widening out to form the bottom of the stuffing-box of the pump cover. Upon the top of this pipe some screws press, which are accessible from the top of the stuffing-box gland; and the packing also aids in keeping down the pipe, the function of which is to retain the valve seat in its place. When the pump bucket has to be examined, the valve seat may be slung with the cover, so as to come up with the same purchase.

Q. Are air pumps sometimes geared down so as to diminish the velocity of the bucket?

A. That has been done in some cases, but the arrangement has never come into general use. Messrs. Thorneycroft, in their fast torpedo-boats, gear down the feed pumps by driving them off a worm wheel, the propelling thread of which is fixed on the screw shaft; and by this arrangement the feed pumps are found to work noiselessly. With the same object they give a very short stroke to the air-pump bucket, and hence, even with very high speeds of engine, the air-pump bucket is not driven with an inconvenient velocity.

Q. What other arrangements for diminishing the shock have been propounded?

A. In some cases where the pistons have been driven very fast the air pump has been worked by an independent engine, which may be driven at any convenient velocity. It has also been proposed to condense the steam in the air pump, and to let the condensing water both into and out of the pump by a slide valve which would work without shock.

Q. Would such an arrangement be suitable in the case of a surface condenser?

A. In the case of a surface condenser the water with which the condensation is performed would have to be cooled by being passed through thin pipes with cold water outside them.

Symington and Bowie, the son and son-in-law of the Symington who made the first steamboat engine, made a trial of this principle in the steamer 'City of Londonderry' about 1835. But the pipes which were placed outside the vessel were supposed to impede her progress, and hence they were removed. The condensation, however, was properly performed, and it was found that after the pipes had been removed, the speed of the vessel was not increased.

Q. Are not air-pump valves now very generally made of indiarubber for engines of every class?

A. They are almost invariably so made if the engines are travelling fast, as in the case of direct-acting screw engines, and they are very often made of large discs or rings of indiarubber, even when the engines travel slowly. A usual arrangement for many purposes is that shown in fig. 90, where both foot and delivery valves are situated in the ends of the pump, and they, as well as the valve in the bucket, are made of indiarubber discs closing on a grating. The trunk in the air pump enables guide rods to be dispensed with. The rod B, to which is connected the link which gives motion to the bucket, is of iron, and to prevent corrosion at the end the brass nut C is applied to the end of it to hinder the contact of the water. The guards, grids and all the other parts of this pump are well-proportioned, but the bucket is without a junk ring to tighten the packing, which is a disadvantage. This pump when at work is set in a slightly inclined position to suit the circumstances in which it is placed, and the foot valve is consequently shown not

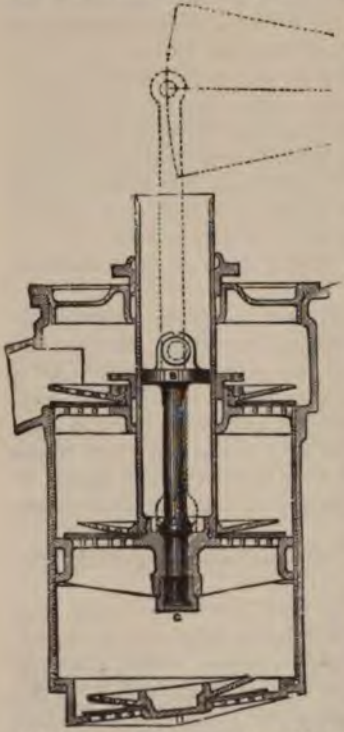


Fig. 90.—Trunk Air Pump. Scale ¾ inch to 1 foot.

in a horizontal position, but at a slight angle therewith. This circumstance, however, is immaterial.

Q. The air pump, when double-acting, has of course inlet and outlet valves at each end?

A. Yes; and the general arrangement of the valves of double-acting air pumps, such as are usual in direct-acting screw engines, is that represented in the figure of Penn's trunk engine, already described in Chapter I. Each inlet and outlet valve consists of a number of indiarubber discs set over a perforated brass plate, and each disc is bound down by a bolt in the middle, which bolt also secures a brass guard set above the disc to prevent it from rising too high. The usual configuration of those valves is that represented in figs. 91, 92, and 93; figs. 91 and 92 being a section and ground plan of the species of valve used by Messrs. Penn, and fig. 93 being a section of that used by Messrs. Maudslay. It is important in these valves to have the indiarubber thick—say about an inch thick for valves eight inches in diameter. It is also advisable to make the central bolts with a nut above and a nut below, and to form the bolt with a counter-sunk neck, so that it will not fall down when the top nut is removed. The lower point of the bolt should be riveted over on the nut to prevent it from unscrewing, and the top end should have a split pin through the point for the same purpose. The hole through which the bolt passes should be tapped, though the bolt is not screwed into it, so that if a bolt breaks a temporary stud may be screwed into the

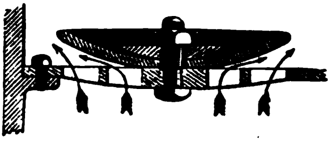


Fig. 91.—Penn's Disc Valve for Air Pump. Section.

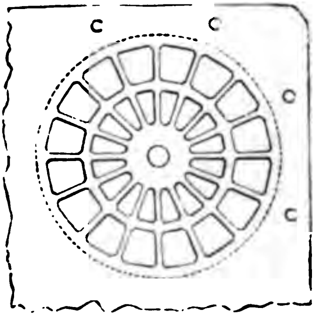


Fig. 92.—Penn's Disc Valve for Air Pump. Ground Plan.

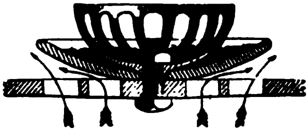


Fig. 93.—Maudslay's Disc Valve for Air Pump. Section.

hole without the necessity of taking out the whole plate. The guard should be large, else the disc may stretch in the central hole until it comes over it; but the guard should not permit too much lift of the valve, else a good deal of the water and air will return into the pump at the return stroke before the valve shuts.

Q. What is the proper area through the valve gratings in double-acting air pumps moving at a high speed?

A. The collective area should be at least equal to the area of the pump piston, and the lower edges of the perforations should be rounded off to afford more free ingress or egress to the water.

Q. Is there much strain thrown on the plates in which the valves are set?

A. A good deal of strain; and in the earlier direct-acting screw engines these plates were nearly in every case made too light. They should be made thick, have strong feathers upon them, and be very securely bolted down. The plate will be very apt to be broken should some of the bolts become loose. Of course all the bolts and split pins, as well as the plates and guards, must be of brass.

Q. How are the plates to be taken out should that become necessary?

A. They are usually taken out through a door in the top of the hot well provided for that purpose, which door should be as large as the plates themselves.

Q. Of what material are condensers usually made?

A. Formerly they were always made of cast iron, but now they are frequently made wholly of brass.

Q. Does the double-acting air pump, employed in many horizontal direct-acting screw engines, produce as good a vacuum as the single-acting air pump usual in paddle engines?

A. It will do so if properly constructed; but I do not know of many double-acting air pumps, with indiarubber valves, which have been properly constructed.

Q. What is the fault of such pumps?

A. The pump frequently works by starts, as if at times it did not draw at all, and then again on a sudden gorged itself with water, so as to throw a great strain upon the working parts. The vacuum, moreover, is by no means so good as it should be, and it is a common vice of horizontal air pumps that the vacuum is defective. I have been at some pains to investigate the causes of this imperfection; and in a sugar-house engine, fitted with pumps like those of a horizontal screw engine, to maintain a vacuum in the pans, I found that a better vacuum was produced when the engine was going slowly than when it was going fast, which is quite the reverse of what was to have been expected, as the hot water which had to be removed by the condensation of the steam proceeding from the pan was a constant quantity. In this engine, too, which was a high-pressure one, the irregularities of the motion consequent upon the fitful catching of the water by the pump, were more conspicuous, as the working of this vacuum pump was the only work that the engine had to perform.

Q. And were you able to discover the cause of these irregularities?

A. The main cause of them I found to be the largeness of the space left between the valve plates in this class of pumps, and out of which there is nothing to press the air or water which may be lying there. It consequently happens, that if there be the slightest leakage of air into the pump, this air is merely compressed, and not expelled, by the advance of the air-pump piston. It expands again to its former bulk on the return of the pump piston, and prevents the water from entering until there is such an accumulation of pressure in the condenser as forces the water into the pump, when the air, being expelled by the water, causes a good vacuum to be momentarily formed in the pump, when it gorges itself by taking a sudden gulp of water. So soon, however, as the pressure falls in the condenser and some more air leaks into the pump, the former imperfect action recurs and is again redressed in the same violent manner.

Q. Is this irregular action of the pump the cause of the imperfect vacuum?

A. It is one cause. Sometimes one end of the pump will alone draw and the other end will be inoperative, although it is equally open to the condenser, and this will chiefly take place at the stuffing-box end, where a leakage of air is more likely to occur. I find however, that even when both ends of the pump are acting equally, and there is no leakage of air at all, the vacuum maintained by a double-acting horizontal pump with indiarubber valves is not so good as that maintained by a single-acting pump of the kind usual in old engines.

Q. Will you specify more precisely what were the results you obtained?

A. When the vacuum pan was exhausted by the pumps without any boiling being carried on in the pan, but only a little cold water being let into it, and also into the pumps to enable them to act in their best manner, it was found that, whereas with the old pump a vacuum of 114 on the sugar-boiler's gauge could be readily obtained, equal to about 29½ inches of mercury, the lowest that could possibly be got with the new horizontal pump was 122 degrees of the sugar-boiler's gauge, or 29 inches of mercury, and to get that the engine must not go faster than 10 or 12 strokes per minute. The proper speed of the engine was 75 strokes per minute, but if allowed to go at that speed the vacuum fell to 130 of the sugar-maker's gauge, or 28½ inches of mercury. When the steam was let into the worms of the pan so as to boil the water in it, the vacuum was 134 at 75 revolutions of the engine, and went down to 132 at 40 revolutions, but rose again to 135, equal to about 28¼ inches of mercury at 20 revolutions.

Q. To what do you attribute the circumstance of a better vacuum being got at low speeds than at high speeds?

A. It is difficult to assign the precise reason, but it appears to be a consequence of the largeness of the vacant space between the valve plates. When the piston of the air-pump is drawn back, the air contained in this large collection of water will cause it to boil up like soda water; and when the piston of the pump is forced forward, this air, instead of being expelled, will be again driven into the water. There will consequently be a quantity of air in the pump which cannot be got rid of at all, and which will impair the vacuum as a matter of course.

Q. What expedient did you adopt to improve the vacuum in the engine to which you have referred?

A. I put blocks of wood on the air-pump piston, which at the end of its stroke projected between the valve plates and forced the water out. I also introduced a cock of water at each end of the pump between the valve plates, to insure the presence of water at each end of the pump to force the air out. With these ameliorations the pump worked steadily, and the vacuum obtained became as good as in the old pump. I had previously introduced an injection cock into each end of the air pump in steam vessels, from which I had obtained advantageous results; and in all horizontal air pumps I would recommend the piston and valve plates to be so constructed that the whole of the water will be expressed by the piston. I would also recommend an injection cock to be introduced at each end of the pump.

PUMPS, COCKS, AND PIPES.

Q. Will you explain the arrangement of the feed pump?

A. In steam vessels, the feed-pump plunger is always of brass, and the barrel of the pump is generally of brass. There should be a considerable clearance between the bottom of the plunger and the bottom of the barrel in the case of engines without surface condensation and operating by injection, as otherwise the bottom of the barrel may be knocked out, should coal dust or any other foreign substance gain admission, as it probably would do if the injection water were drawn at any time from the bilge of the vessel, as is usually done if the vessel springs a leak or ships much water. The valves of the feed pump in marine engines are generally of the spindle kind, and are most conveniently arranged in a chest, which may be attached in any accessible position to the side of the hot well. There are three side nozzles upon this chest, of which the lowest one leads to the pump, and the middle one to the boiler. The pipe leading to the pump is a suction pipe when the plunger ascends, and a forcing pipe when the plunger descends. The plunger in ascending draws the water out of the hot well through the lowest of the valves, and in descending forces it through the centre valve into the space above it, which communicates with the feed pipe. Should the feed cock be shut so as to prevent any feed water from passing through it, the water will raise the topmost valve, which is loaded to a pressure considerably above the pressure of the steam, and escape back into the hot well.

Q. Will you describe what precautions are to be observed in the construction of the cocks used in engines?

A. All the cocks about an engine should be provided with bottoms and stuffing-boxes, and reliance should never be placed upon a single bolt passing through a bottom washer for keeping the plug in its place, in the case of any cock communicating with the boiler; for a great strain is thrown upon that bolt if the pressure of the steam be high, and if the plug be made with much taper; and should the bolt break, or the thread strip, the plug will fly out, and persons standing near may be scalded to death. In large cocks, it appears the preferable plan to cast the bottoms in; and the metal of which all the cocks about a marine engine are made should be of the same quality as that used in the composition of the brasses, and should be without lead, or other deteriorating material. In some cases the bottoms of cocks are burnt in with hard solder, but this method cannot be depended upon, as the solder is softened and wasted away, and in time the bottom leaks, or is forced out. The stuffing-box of cocks should be made of adequate depth, and the gland should be secured by means of four strong copper bolts. The taper of blow-off cocks is an important element in their construction; as, if the taper be too great, the plugs will have a continual tendency to rise, which, if the packing be slack, will enable grit to get between the faces, while, if the taper be too little, the plug will be liable to jam, and a few times grinding will sink it so far through the shell that the waterways will no longer correspond. One-eighth of an inch deviation from the perpendicular for every inch in height is a common angle for the side of the cock, which corresponds with one quarter of an inch difference of diameter in an inch of height; but perhaps a somewhat greater taper than this, or one-third of an inch difference in diameter for every inch of height, is a preferable proportion. The bottom of the plug must be always kept a small distance above the bottom of the shell, and an adequate surface must be left above and below the waterway to prevent leakage. Cocks formed according to these directions will be found to operate satisfactorily in practice, while they will occasion perpetual trouble if there be any malformation.

Q. What is the best arrangement and configuration of the blow-off cocks?

A. The blow-off cocks of a boiler are generally placed some distance from the boiler; but it appears preferable that they should be placed quite close to it, as else there are no means of shutting off the water from the blow-off pipes, should fracture or leakage there occur. Every boiler must be furnished with a blow-off cock of its own, independently of the main blow-off cocks on the ship's sides, so that the boilers may be blown off separately, and may be shut off from one another. The preferable arrangement appears to be, to cast upon each blow-off cock a bend for attaching the cock to the bottom of the boiler, and the plug should stand about an inch in advance of the front of the boiler, so that it may be removed, or reground, with facility. The general arrangement of the blow-off pipes is to run a main blow-off pipe beneath the floor plates, across the ship, at the end of the engines, and into this pipe to lead a separate pipe, furnished with a cock, from each boiler. The main blow-off pipe, where it penetrates the ship's sides, is furnished with a cock; and in modern steam vessels Kingston's valves are also used, which consist of a spindle or plate valve, fitted to the exterior of the ship, so that if the internal pipe or cock breaks, the external valve will still be operative. Some expedient of this kind is almost necessary, as the blow-off cocks require occasional re-grinding, and the sea cocks cannot be reground without putting the vessel into dock, except by the use of Kingston's valves, or some equivalent expedient.

Q. What is the proper construction and situation of the injection cocks, and waste water valves, in the case of engines condensing by a jet of salt water?

A. The sea injection cocks are usually made in the same fashion as the sea blow-off cocks, and of about the same size, or rather larger. The injection water is generally admitted to the condenser by means of a slide valve, but a cock appears to be preferable, as it is more easily opened, and has not any disposition to shut of its own accord. In paddle vessels the sea injection pipes should be put through the ship's sides in advance of the paddles, so that the water drawn in may not be injuriously charged with air. The waste water pipe passing from the hot well through the vessel's side is provided with a stop valve, called the discharge valve, which is usually made of the spindle kind, so as to open when the water coming from the air pump presses against it. In some cases this valve is a sluice valve, but the hot well is then almost sure to be split, if the engine be set on without the valve having been opened. The opening of the waste water pipe should always be above the load water line, as it will otherwise be difficult to prevent leakage through the engine into the ship when the vessel is lying in harbour.

Q. What is the best arrangement of gauge cocks and glass gauges?

A. Gauge cocks are generally very inartificially made, and occasion needless annoyance. They are rarely made with bottoms or with stuffing-boxes, and in the case of vessels using salt water in the boilers are consequently, for the most part, adorned with stalactites of salt after a short period of service. The water discharged from them, too, from the want of a proper conduit, disfigures the front of the boiler, and adds to the corrosion in the ash pits. It is a preferable practice to apply the gauge cocks and glass tube appertaining to each boiler to a single upright tube, connected suitably with the boiler, and the water flowing from the cocks should be directed downwards into a funnel tube communicating with the bilge. The cocks of the glass tubes, as well as of the gauge cocks, should be furnished with stuffing-boxes and with bottoms unless the water enters through the bottom of the plug, which in gauge cocks is sometimes the case. The glass gauge tubes should always be fitted with a cock at each neck communicating with the boiler, so that the water and steam may be shut off if the tube breaks; and the cocks should be so made as to admit of the tubes being blown through with steam to clear them, as in muddy water they will become so soiled that the water cannot be seen. The gauge cocks frequently have pipes running up within the boiler, to the end that a high water level may be made consistent with an easily accessible position of the gauge cocks themselves. With the glass tubes, however, this species of arrangement is not possible, and the glass tubes must always be placed in the position of the water level?

Q. What is the proper material of the pipes in steam vessels?

A. Most of the pipes of marine engines should be made of copper. The steam pipes and waste water pipes are of copper. Cast iron blow-off pipes have in some cases been employed, but they are liable to fracture, and are dangerous. The blow-off and feed pipes should be of copper, but the waste steam pipe may be of galvanised iron. Every pipe passing through the ship's side, and every pipe fixed at both ends, and liable to be heated and cooled, should be furnished with a faucet or expansive joint. In the distribution of the faucets of the pipes exposed to pressure, care must be taken that they be so placed that the parts of the pipe cannot be forced asunder, or turned round by the strain, as serious accidents have occurred from the neglect of this precaution.

Q. What is the best mode of making pipes tight where they penetrate the ship's side?

A. In wooden vessels the pipes where they pierce the ship's sides should be made tight, as follows:—The hole being cut, a short piece of lead pipe, with a broad flange at one end, should be fitted into it, the place having been previously smeared with white lead, and the pipe should then be beaten on the inside, until it comes into close contact all around with the wood. A loose flange should next be slipped over the projecting end of the lead pipe, to which it should be soldered, and the flanges should both be nailed to the timber with scrupper nails, white lead having been previously spread underneath. This method of procedure, it is clear, prevents the possibility of leakage down through the timbers; and all, therefore, that has to be guarded against after this precaution, is to prevent leakage into the ship. To accomplish this object, let the pipe which it is desired to attach be put through the leaden hawse, and let the space between the pipe and the lead be packed with gasket and white lead to which a little olive oil has been added. The pipe must have a flange upon it to close the hole in the ship's side ; the packing must then be driven in from the outside, and be kept in by means of a gland secured with bolts passing through the ship's side. If the pipe is below the water line the gland must be of brass, but for the waste water pipe a cast iron gland will answer. This method of securing pipes penetrating the side, however, though the best for wooden vessels, will, it is clear, fail to apply to iron ones. In the case of iron vessels, it appears to be the best practice to attach a short iron nozzle, projecting inwards from the skin, for the attachment of every pipe below the water line, as the copper or brass would waste the iron of the skin if the attachment were made in the way usual for wooden ships.

DETAILS OF THE SCREW AND SCREW SHAFT.

Q. What is the best method of fixing the screw upon the shaft?

A. The best way is to cut two large grooves in the shaft coming up to a square, and two corresponding grooves or key seats in the screw boss opposite the arms. Fit into the grooves on the shaft keys with heads, the length of which is equal to half the depth of the boss, and with the ends of the keys bearing against the ends of the grooves in the shaft. Then ship on the propeller, and drive other keys of an equal length from the other side of the boss, so that the points of the keys will nearly meet in the middle ; next burr up the edges of the grooves upon the heads of the keys, to prevent them from working back ; and finally tap a bolt into the side of the boss to penetrate the shaft. Propellers so fitted will never get slack.

Q. What is the best way of fitting in the screw pipe at the stern?

A. It should have projecting rings, which should be turned ; and cast iron pieces with holes in them, bored out to the sizes of these rings, should be secured to the stern frames of the vessel, and the pipe be then shipped through all. Before this is done, however, the stern post must be bored out by a template to fit the pipe, and the pipe is to be secured at the end to the stern post, either by a great external nut of cast iron, or by bolts passing through the stern post and through lugs on the pipe. The pipe is generally lined with *lignum vitæ*, and the shaft where bearing on the *lignum vitæ* is covered with brass.

Q. How is the hole formed in the deadwood of the ship in which the screw works?

A. A great frame of malleable iron, the size of the hole, is first set up, and the plating of the ship is brought to the edge of this hole, and is riveted through the frame. It is important to secure this frame very firmly to the rest of the ship, with which view it is advisable to form a great palm, like the palm of a vice, on its inner superior corner, which, projecting into the ship, may be secured by breast-hook plates to the sides, whereby the strain which the screw causes will be distributed over the stern, instead of being concentrated on the rivets of the frame.

Q. Is this frame to which the plating is riveted of considerable thickness, so as to have the necessary strength?

A. It is.

Q. And is the diameter of the rivets the same as that which prevails in the other parts of the plating of the ship?

A. Yes.

Q. Then how can the rivets be tight, seeing that they have to pass through a thick piece of iron with a comparatively thin plate on each side?

A. They would not be tight if put in red hot and riveted up in the usual fashion. But these particular rivets are usually turned, and the holes are widened and made quite true by hand before the rivets are inserted. The riveting is done without heat and the rivets are usually of softened steel.

Q. Are there several lengths of screw shaft?

A. There are.

Q. How, then, are these secured to one another?

A. The best mode of securing the several lengths of shaft together is by forging the shafts with flanges at the ends, which are connected together by bolts, say six strong bolts in each in the case of a shaft of moderate size, but eight or ten bolts in very large shafts. But the abutting ends of the shafts should be slightly rounded to permit a slight side play, as the shaft will bend a little from its own weight between the bearings, and it is proper to make the structure such as to permit this.

Q. How is the thrust of the shaft received?

A. In some cases it is received on a number of metal discs set in a box containing oil; and should one of these discs stick fast from friction, the others will be free to revolve. In this arrangement, which is represented in fig. 94, A is the discs, and they can be slightly set up by the wedge B. Another arrangement more generally used is that represented in figs. 95 and 96. It is a good practice to make the thrust plummer block with a very long sole in the direction

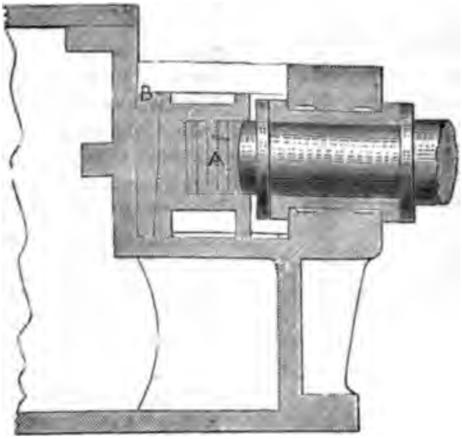


Fig. 94.—End of the Screw Shaft of Correo, showing the Mode of receiving the Thrust. A, discs; B, tightening wedge.

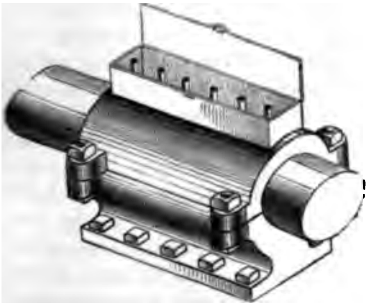


Fig. 95.—Plummer Block for receiving Thrust of Screw, as used by Messrs. Penn.

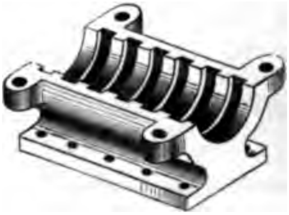


Fig. 96.—Plummer Block with Cap removed.

of the shaft, so as to obviate any risk of canting or springing forward when the strain is applied, as such a circumstance, if occurring even to a slight extent, would be very likely to cause the bearing to heat.

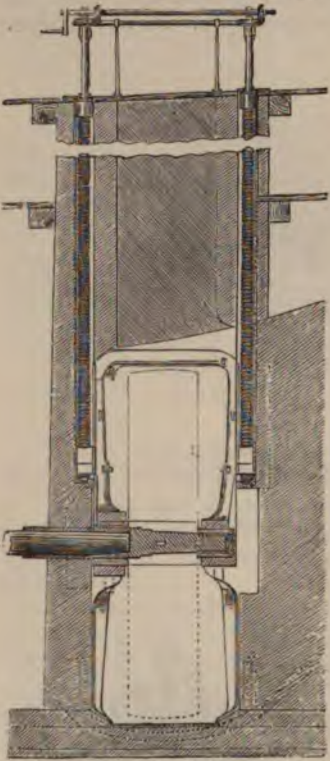


Fig. 97.—Elevation of Apparatus for lifting Screw of 'Dauntless.'

Q. Are there not arrangements existing in some vessels for enabling the screw to be lifted out of the water while the vessel is at sea?

A. There are; but such arrangements are not usual in merchant vessels, and have now been discarded in war vessels. Nevertheless, they constitute an object of legitimate curiosity. One form of apparatus for this purpose is that represented in fig. 97. The screw is set on a short shaft in the middle of a sliding frame, which can be raised or lowered in grooves like a window, and the screw shaft within the ship can be protruded or withdrawn by appropriate mechanism, so as to engage or leave free this short shaft as may be required. When the screw has to be lifted, the screw shaft is drawn into the vessel, leaving the short shaft free to be raised up by the sliding frame, and the frame is raised by long screws turned round by a winch purchase on deck. A chain or rope, however, is better for the purpose of raising this frame than long screws; but the frame should in such case be provided with pall catches like those of a windlass, which, if the rope should break, will prevent the screw from falling down with an injurious shock.

FITTING AND FIXING MARINE ENGINES.

Q. Will you explain the method of putting engines into a steam vessel?

A. As an illustration of this operation it may be advisable to take the case of a side lever engine, as on the whole the most complex example that could be presented, and those who understand how to fit such engines will have no difficulty with any other kind. The method of proceeding is as follows:—First measure across from the inside of paddle bearers to the centre of the ship, to make sure that the central line, running in a fore and aft direction on the deck or beams, usually drawn by the carpenter as immediately over the keel, is really in the centre. Stretch a line across between the paddle bearers in the direction of the shaft. To this line, in the centre of the ship where the fore and aft mark has been made, apply a square with arms six or eight feet long, and bring a line stretched perpendicularly from the deck to the keelson, accurately to the edge of the square. The lower point of the line where it touches the keelson will be immediately beneath the marks made upon the deck. If this point does not come in the centre of the keelson, it will be better to shift it a little, so as to bring it to the centre, altering the mark upon the deck correspondingly, provided either paddle shaft will admit of this being done—one of the paddle brackets being, if necessary, packed behind with wood, to give it an additional projection from the side of the paddle bearer. Continue the line fore and aft upon the keelson as nearly as can be judged in the centre of the ship. Stretch another line fore and aft through the mark upon the deck, and look it out of winding with the line upon the keelson. Fix upon any two points equally distant from the centre, in the line stretched transversely in the direction of the the shaft; and from those points, as centres, and with any convenient radius, sweep across the fore and aft line to see that the two are at right angles; and, if not, shift the transverse line a little to make them so. From the transverse line next let fall a line upon each outside keelson, bringing the edge of the square to the line, the other edge resting on the keelson. A point will thus be got on each outside keelson perpendicularly beneath the transverse line running in the direction of the shaft, and a line drawn between those two points will be directly below the shaft. To this line the line of the shaft marked on the sole plate has to be brought, care being taken, at the same time, that the right distance is preserved between the fore and aft line upon the sole plate, and the fore and aft line upon the central keelson.

Q. Of course the keelsons have first to be properly prepared?

A. In a wooden vessel, before any part of the machinery is put in, the keelsons should be dubbed fair and straight, and be looked out of winding by means of two straight edges placed across them. The art of placing engines in a ship is more a piece of plain common sense than any other feat of engineering, and every man of intelligence may easily settle a method of procedure for himself. Plumb lines and spirit levels, it is obvious, cannot be employed on board a vessel, and the problem consists in so placing the sole plates, without these aids, that the paddle shaft will not stand awry across the vessel, nor be carried forward beyond its place by the framing shouldering up more than was expected. As a plumb line cannot be used, recourse must be had to a square; and it will signify nothing at what angle with the deck the keelsons run, so long as the line of the shaft across the keelsons is squared down from the shaft centre. The sole plates being fixed, there is no difficulty in setting the other parts of the engine in their proper places upon them. The paddle wheels must be hung from the top of the paddle box to enable the shaft to be rove through them, and the cross stays between the engines should be fixed in when the vessel is afloat, as the vessel will alter her form when aground. To try whether the shafts are in a line, turn the paddle wheels, and try if the distance between the cranks is the same at the upper and under and the two horizontal centres; if not, move the end of the paddle shaft up or down, backwards or forwards, until the distance between the cranks at all the four centres is the same.

Q. In what manner are the engines of a steam vessel secured to the hull?

A. The engines of a steamer are secured to the hull by means of bolts called holding down bolts, and in wooden vessels a good deal of trouble is caused by these bolts, which are generally made of iron. Sometimes they go though the bottom of the ship, and at other times they merely go through the keelsons,—a recess being made in the floor or timbers to admit of the introduction of a nut. The iron, however, wears rapidly away in both cases, even though the bolts are tinned; and it has been found the preferable method to make such of the bolts as pass through the bottom, or enter the bilge, of Muntz's metal, or of copper. In a side lever engine, four

Muntz's metal bolts may be put through the bottom at the crank end of the framing of each engine, four more at the main centre, and four more at the cylinder, making twelve through bolts to each engine; and it is more convenient to make these bolts with a nut at each end, as in that case the bolts may be dropped down from the inside, and the necessity is obviated of putting the vessel on very high blocks in the dock, in order to give room to put the bolts up from the bottom. The remainder of the holding down bolts may be of iron, and may, by means of a square neck, be screwed into the timber of the keelsons as wood screws—the upper part being furnished with a nut which may be screwed down upon the sole plate, so soon as the wood screw portion is in its place. If the cylinder be a fixed one it should be bolted down to the sole plate by as many bolts as are employed to attach the cylinder cover, and they should be of copper or brass, in any situation that is not easily accessible. In the case of iron vessels the method of securing the engines to the hull is much simpler, as the sole plates have only to be firmly bolted by iron bolts to the iron keelsons.

Q. If the engines become loose in wooden vessels, how do you refix them?

A. It is difficult to fix engines effectually which have once begun to work in the ship, for in time the surface of the wooden keelsons on which the engines bear becomes worn uneven, and the engines necessarily rock upon it. As a general rule, the bolts attaching the engines to the keelsons are too few and of too large a diameter: it would be preferable to have smaller bolts, and a greater number of them. In addition to the bolts going through the keelsons or the vessel's bottom, there should be a large number of wood screws securing the sole plate to the keelson, and a large number of bolts securing the various parts of the engine to the sole plate. In iron vessels, holding-down bolts passing through the bottom are not expedient; and there the engine has merely to be secured to the iron plate of the keelsons, which are made hollow to admit of a more effectual attachment.

Q. What are the proper proportions of bolts?

A. In well-formed bolts, the spiral groove penetrates about one-twelfth of the diameter of the cylinder round which it winds, so that the diameter of the solid cylinder which remains is five-sixths of the diameter over the thread. If the strain to which iron may be safely subjected in machinery is one-fifteenth of its utmost strength, or 4,000 lbs. on the square inch, then 2,180 lbs. may be sustained by a screw an inch in diameter, at the outside of the threads. The necessary strength of the holding-down bolts may easily be computed, when the elevating force of the piston or main centre is known; but it is expedient very much to exceed this strength in practice, on account of the elasticity of the keelsons, the liability to corrosion, and other causes. The elevating force of the piston on the main centre is twice as great as the maximum force on the piston, by reason of the intervention of the side levers.

THE LOCOMOTIVE ENGINE.

Q. What is the amount of tractive force requisite to draw carriages on railways?

A. Upon well-formed railways with carriages of good construction, the average tractive force required for low speeds is about $7\frac{1}{2}$ lbs. per ton, or $\frac{1}{300}$th of the load, though in some experimental cases, where particular care was taken to obtain a favourable result, the tractive force has been reduced as low as $\frac{1}{500}$th of the load. At low speeds the whole of the tractive force is expended in overcoming the friction, which is made up partly of the friction of attrition in the axles, and partly of the rolling friction, or the obstruction to the rolling of the wheels upon the rail. The rolling friction is very small when the surfaces are smooth, and in the case of railway carriages does not exceed $\frac{1}{1000}$th of the load; whereas the draught on common roads of good construction, which is chiefly made up of the rolling friction, is as much as $\frac{1}{36}$th of the load.

Q. In reference to friction you have already stated that the friction of iron sliding upon brass, which has been oiled and then wiped dry, so that no film of oil is interposed, is about $\frac{1}{11}$th of the pressure, but that in machines in actual operation, where there is a film of oil between the rubbing surfaces, the friction is only about one-third of this amount, or $\frac{1}{33}$rd of the weight. How then can the tractive resistance of locomotives at low speeds, which you say is entirely made up of friction, be so little as $\frac{1}{500}$th of the weight?

A. I did not state that the resistance to traction was $\frac{1}{500}$th of the weight upon an average—to which condition the answer given to a previous question must be understood to apply—but I stated that the average traction was about $\frac{1}{300}$th of the load, which nearly agrees with my former statement. If the total friction be $\frac{1}{300}$th of the load, and the rolling friction be $\frac{1}{1000}$th of the load, then the friction of attrition must be $\frac{1}{429}$th of the load; and if the diameter of the wheels be 36 in., and the diameter of the axles be 3 in., which are common proportions, the friction of attrition must be increased in the proportion of 36 to 3, or 12 times, to represent the friction of the rubbing surface when moving with the velocity of the carriage. $\frac{12}{429}$ths are about $\frac{1}{35}$th of the load, which does not differ much from the proportion of $\frac{1}{33}$rd, as previously determined.

Q. What is the amount of adhesion of the wheels upon the rails?

A. The adhesion of the wheels upon the rails is about $\frac{1}{6}$th of the weight when the rails are clean, or either perfectly wet or perfectly dry; but when the rails are half-wet or greasy, the adhesion is not more than $\frac{1}{10}$th or $\frac{1}{12}$th of the weight or pressure upon the wheels. The weight of a locomotive of modern construction in working order varies from 30 to 35 tons. But some of the foreign goods locomotives weigh 100 tons or more.

Q. And what is its cost and average performance?

A. The cost of a common narrow-gauge locomotive, of average power, varies from 1,900*l.* to 2,200*l.*; but a first-class engine, working steam of 140 to 160 lbs., and running express trains at 50 miles per hour, will cost 2,800*l.* or 3,000*l.* Such an engine will weigh 35 tons, or more, and usually carries about half the weight on a single pair of wheels. But it is preferable to use a lower carriage set beneath the engine, or a bogie, as it is called, to distribute the weight better over the road, and to enable the axles to adjust themselves into a position at right angles with the rails.

Q. Does the expense of traction increase much with an increased speed?

A. Yes; it increases very rapidly, partly from the undulation of the earth when a heavy train passes over it at a high velocity, and partly from the resistance of the atmosphere and concussion, which constitute the greatest of the impediments to motion at high speeds. At a speed of 30 miles an hour, the atmospheric resistance has been found in some cases to amount to about 12 lbs. a ton; and in side winds the resistance even exceeds this amount, partly in consequence of the additional friction caused from the flanges of the wheels being forced against the rails, and partly because the wind catches to a certain extent the front of every carriage. At a speed of 30 miles an hour, an engine evaporating 200 cubic feet of water in the hour, and exerting about 200 indicated horses power, will draw a load of 110 tons. Taking the friction of the train at 7½ lbs per ton, or 825 lbs. operating at the circumference of the driving wheel,—which, with 5 ft. 6 in. wheels, and 18 in. stroke, is equivalent to 4,757 lbs. upon the pistons—and taking the resistance of the blast pipe at 6 lbs. per square inch of the pistons, and the friction of the engine unloaded at 1 lb. per square inch, which, with pistons 12 inches in diameter, amount together to 1,582 lbs., and reckoning the increased friction of the engine due to the load at ⅐th of the load, as in some cases it has been found experimentally to be, though a much less proportion than this would probably be a nearer average, we have 7018·4 lbs. for the total load upon the pistons. At 30 miles an hour the speed of the pistons will be 457·8 feet per minute, and 7018·4 lbs. multiplied by 457·8 feet per minute are equal to 3,213,023·5 lbs. raised one foot high in the minute, which divided by 33,000 gives 97·3 horses power as the power which would draw 110 tons upon a railway at a speed of 30 miles an hour, if there were no atmospheric resistance. The atmospheric resistance is at the rate of 12 lbs. a ton, with a load of 110 tons, equal to 1,320 lbs., moving at a speed of 30 miles an hour, which, when reduced, becomes 105·8 horses power, and this, added to 97·3, makes 203·1, instead of 200 horses power, as ascertained by a reference to the evaporative power of the boiler. This amount of atmospheric resistance, however, exceeds the average, and in some of the experiments for ascertaining the atmospheric resistance, a part of the resistance due to the curves and irregularities of the line has been counted as part of the atmospheric resistance.

Q. Is the resistance per ton of the engine the same as the resistance per ton of the train?

A. No; it is more, since the engine has not merely the resistance of the atmosphere and of the wheels to encounter, but the resistance of the machinery besides. According to Sir D. Gooch's experiments upon a train weighing 100 tons, the resistance of the engine and tender at 13·1 miles per hour was found by the indicator to be 12·38 lbs.; the resistance per ton of the train, as ascertained by the dynamometer, was at the same speed 7·56 lbs., and the average resistance of locomotive and train was 9·04 lbs. At 20·2 miles per hour these resistances respectively became 19·0, 8·19, and 12·2 lbs. At 44·1 miles per hour the resistances became 34·0, 21·10, and 25·5 lbs., and at 57·4 miles an hour they became 35·5, 17·81, and 23·8 lbs.

Q. Is it not maintained that the resistance of the atmosphere to the progress of railway trains increases as the square of the velocity?

A. The atmospheric resistance, no doubt, increases as the square of the velocity, and the power, therefore, necessary to overcome it will increase as the cube of the velocity, since in doubling the speed four times the power must be expended in overcoming the atmospheric resistance in half the time. At low speeds, the resistance does not increase very rapidly ; but at high speeds, the total resistance will vary nearly as the square of the velocity if the line be rough, but will vary more nearly as the velocity merely if it be very smooth. Thus, the resistance of a train, including locomotive and tender, will at 15 miles an hour be about 9·3 lbs. per ton ; at 30 miles an hour it will be 13·2 lbs. per ton ; and at 60 miles an hour 29 lbs. per ton. If we suppose the same law of progression to continue up to 120 miles an hour, the resistance at that speed will be 92·2 lbs. per ton, and at 240 miles an hour the resistance will be 344·8 lbs. per ton. Thus, in doubling the speed from 60 to 120 miles per hour, the resistance does not fall much short of being increased fourfold, and the same remark applies to the increase of the speed from 120 to 240 miles an hour. But it is impossible to rely upon such inferences, as in locomotives there may, for aught we know, be a similar law to that shown to exist in swift torpedo-boats, where the resistance becomes less at very high speeds. The following rule, supposing the line to be in good order and free from curves, has been found to give corect results for such speeds as those of which we have any experience:—To find the total resistance of the engine, tender, and train in pounds per ton, at any given speed: Square the speed in miles per hour; divide it by 171, and add 8 to the quotient. The result is the total resistance at the rails in lbs. per ton. But this result supposes the line to be of the usual roughness of railway lines, and on very smooth lines the increase of resistance will be less rapid.

Q. How comes it that the resistance of fluids increases as the square of the velocity, instead of the velocity simply?

A. Because the height necessary to generate the velocity with which the moving object strikes the fluid, or the fluid strikes the object, increases as the *square* of the velocity, and the resistance or the weight of a column of any fluid varies as the height. A falling body, as has been already explained, to have acquired twice the velocity, must have fallen through four times the height. The velocity generated by a column of any fluid is equal to that acquired by a body falling through the height of the column ; and it is therefore clear that the pressure due to any given velocity must be as the square of that velocity, the pressure being in every case as twice the altitude of the column. The work done, however, by a stream of air or other fluid in a given time will vary as the cube of the velocity; for, if the velocity of a stream of air be doubled, there will not only be four times the pressure exerted per square foot, but twice the quantity of air will be employed; and in windmills, accordingly, it is found that the work done varies nearly as the cube of the velocity of the wind. If, however, the work done by *a given quantity* of air moving at different speeds be considered, it will vary as the squares of the speeds.

Q. But in a case where there is no work done, and the resistance varies as the square of the speed, should not the power requisite to overcome that resistance vary as the square of the speed?

A. It should, if you consider the resistance over a given distance, and not the resistance during a given time. Supposing the resistance of a railway train to increase as the square of the speed, it would take four times the power, so far as atmospheric resistance is concerned, to accomplish a mile at the rate of 60 miles an hour, that it would take to accomplish a mile at 30 miles an hour; but in the former case there would be twice the number of miles accomplished in the same time, so that when the velocity of the train was doubled, we should require an engine that was capable of overcoming four times the resistance at twice the speed, or, in other words, that was capable of exerting eight times the power, so far as regards the element of atmospheric resistance. We know by experience, however, that it is easier to attain high speeds on the railways than in steam vessels, where the resistance does increase nearly as the square of the speed. But this law holds only up to a certain point. Beyond that the resistance increases more nearly as the cube, and beyond that again more nearly as the simple velocity, owing in part probably to diminished immersion.

Q. Will you describe generally the arrangement of a locomotive engine?

A. The boiler and engine are hung upon a framework set on wheels, and, together with this frame or carriage, constitute what is commonly called the locomotive. Behind the locomotive runs another carriage, called the tender, for holding fuel and water. A common mode of connecting the engine and tender is by means of a rigid bar, with an eye at each end through which pins are passed. Between the engine and tender, however, buffers should always be interposed, as their pressure contributes greatly to prevent oscillation and other irregular motions of the engine.

Q. How is the framing of a locomotive usually constructed?

A. All locomotives are now made with the framing which supports the machinery situated within the wheels. But for some years a vehement controversy was maintained respecting the relative merits of outside and inside framing, which has terminated, however, in the universal adoption of the inside framing. It is difficult, in engines intended for the narrow gauge, to get cylinders within the framing of sufficient diameter to meet the exigencies of railway locomotion. By casting both cylinders in a piece, however, a considerable amount of room may be made available to increase their diameters. It is very desirable that the cylinders of locomotives should be as large as possible, so that expansion may be adopted to a large extent; and with any given speed of piston, the power of an engine either to draw heavy loads or achieve high velocities, will be increased with every increase of the dimensions of the cylinder. The framing of locomotives, to which the boiler and machinery are attached, and which rests upon the springs situated above the axles, is formed generally of malleable iron, but formerly the side frames sometimes consisted of oak with iron plates riveted on each side. The guard plates are in these cases generally of equal length, the frames being curved upwards to pass over the driving axle. Hard cast iron blocks are riveted between the guard plates to serve as guides for the axle bushes.

Q. What is the nature and arrangement of the springs of locomotives?

A. The springs are of the ordinary carriage kind, with plates connected at the centre, and allowed to slide on each other at their ends. The upper plate terminates in two eyes, through each of which passes a pin, which also passes through the jaws of the bridle, connected by a double threaded screw to another bridle, which is jointed to the framing; the centre of the spring rests upon the axle-box. Sometimes the springs are placed between the guard plates, and below the framing which rests upon their extremities. One species of spring which has gained a considerable introduction consists of a number of flat steel plates, with a piece of metal or other substance interposed between them at the centre, leaving the ends standing apart. It would be preferable, perhaps, to make the plates of a common spring with different curves, so that the leaves, though in contact at the centre, would not be in contact at the ends with light loads, but would be brought into contact gradually, as the strain comes on. A spring would thus be obtained that was suitable for all loads.

Q. What is the difference between inside and outside cylinder engines?

A. Outside cylinders are so designated when placed upon the outside of the framing, with their connecting rods operating upon pins in the driving wheels; while the inside cylinders are situated within the framing, and the connecting rods attach themselves to cranks in the driving axle.

Q. Whether are inside or outside cylinder engines to be preferred?

A. A diversity of opinion obtains as to the relative merits of outside and inside cylinders. The chief objection to outside cylinders is, that they occasion a sinuous motion in the engine which is apt to send the train off the rails; but this action may be made less perceptible, or be remedied altogether, by placing a weight upon one side of the wheels, the momentum of which will just balance the momentum of the piston and its connections. The sinuous or rocking motion of locomotives is traceable to the arrested momentum of the piston and its attachments at every stroke of the engine, and the effect of the pressure thus created will be more operative in inducing oscillation the farther it is exerted from the central line of the engine.

Q. As the question of the locomotive boiler has been already disposed of in discussing the question of boilers in general, it now only remains to inquire into the subject of the engine, and we may commence with the cylinders. Will you state the arrangement and construction of the cylinders of a locomotive and their connections?

A. The cylinders are placed in the same horizontal plane as the axle of the driving wheels, and the connecting rod which is attached to the piston rod engages either a crank in the driving axle or a pin in the driving wheel, according as the cylinders are inside or outside of the framework. The cylinders are generally made an inch longer than the stroke, or there is half an inch of clearance at each end of the cylinder, to permit the springs of the vehicle to act without causing the piston to strike the top or bottom of the cylinder. The thickness of metal of the cylinder ends is usually about a third more than the thickness of the cylinder itself, and both ends are generally made removable. The priming of the boiler, when it occurs, is very injurious to the cylinders and valves of locomotives, especially if the water be sandy, as the grit carried over by the steam wears the rubbing surfaces rapidly away. The face of the cylinder on which the valve works is raised a little above the metal around it, both to facilitate the operation of forming the face and with the view of enabling any foreign substance deposited on the face to be pushed aside by the valve into the less elevated part, where it may lie without occasioning any further disturbance. The valve casing is sometimes cast upon the cylinder, and it is generally covered with a door which may be removed to permit the inspection of the faces. In some valve casings the top as well as the back is removable, which admits of the valve and valve bridle being removed with greater facility. A cock is placed at each end of locomotive cylinders, to allow the water to be discharged which accumulates in the cylinder from priming or condensation ; and the four cocks of the two cylinders are usually connected together, so that by turning a handle the whole are opened at once. Of course there are variations in the arrangements here described in different engines, and outside cylinders cannot always be got into exactly the same horizontal plane as the axle.

Q. What limits the diameter of the cylinders?

A. The distance between the frames, which in its turn is determined by the gauge of the railway.

Q. What kind of piston is used in locomotives ?

A. The variety of pistons employed in locomotives is very great, and sometimes even the more complicated kinds are found to work very satisfactorily ; but, in general, those pistons which consist of a single ring and tongue piece, or of two single rings set one above the other, so as to break joint, are preferable to those which consist of many pieces. A common method is to forge the piston upon the piston rod, and to turn a few grooves in the rim, into which rings are put.

Q. Will you explain the mode of connecting the piston rod with the connecting rod ?

A. The piston rods of all engines are now generally made of steel ; and in locomotive engines the diameter of the piston rod is about one-seventh of the diameter of the cylinder, and it is formed of tilted steel. Formerly the piston was attached to the piston rod by a cone and cutter, or screw, as in land engines ; but the cone was turned the reverse way, to make it more easy to remove the piston through the end of the cylinder. The top of the piston rod is secured with a cutter into a socket with jaws, through the holes of which a cross head passes, which is embraced between the jaws by the small end of the connecting rod, while the ends of the cross head move in guides. Between the piston rod clutch and the guide blocks, the feed pump rod joins the cross head in some engines.

Q. What kind of guides is employed for the end of the piston rod?

A. The guides are formed of steel plates attached to the framing, between which work the guide blocks, fixed on the ends of the cross head, which have flanges bearing against the inner edges of the guides. Steel guides are better than iron ones. Most makers attach their guides at one end to a cross stay, and at the other to lugs on the cylinder cover; and they are made stronger in the middle than at the ends. For all locomotives the arrangements for keeping dust out of the guides and other working parts of the engine are very inadequate, and it would be proper to have them boxed up so hermetically as to exclude dust; and also to have them effectually lubricated by petroleum or other cheap oil, by the aid of a circulating pump, which would send the oil which had drained from the bearings into a reservoir back through pipes to the bearings.

Q. Is any provision made for keeping the connecting rod always of the same length?

A. In every kind of locomotive it is very desirable that the length of the connecting rod should remain invariable, in spite of the wear of the brasses, for there is a danger of the piston striking against the cover of the cylinder if it be shortened, as the clearance is left as small as possible in order to economise steam. In some engines the strap encircling the crank pin is fixed immovably to the connecting rod by dovetailed keys, and a bolt passes through the keys, rod, and strap, to prevent the dovetail keys from working out. The brass is tightened by a gib and cutter, which is kept from working loose by three pinching screws and a cross pin or cutter through the point. The effect of this arrangement is to lengthen the rod, but at the cross head end of the rod the elongation is neutralised by making the strap loose, so that in tightening the brass the rod is shortened by an amount equal to its elongation at the crank pin end. The tightening here is also effected by a gib and cutter, which is kept from working loose by two pinching screws pressing on the side of the cutter. Both journals of the connecting rod are furnished with oil cups, having a small tube in the centre with siphon wicks. The connecting rod is a thick flat bar, with its edges rounded.

Q. How is the cranked axle of locomotives constructed?

A. The cranked axle of locomotives is now usually made of steel, with two cranks forged upon it towards the middle of its length, at a distance from each other answerable to the distance between the cylinders. Bosses are made on the axle for the wheels to be keyed upon, and bearings for the support of the framing. The axle is cast in an ingot, and afterwards forged into shape, with the crank blocks in the same plane; and the axle is then twisted to bring the cranks into the proper relative positions. The blocks are then cut out to form the cranks. In engines with outside cylinders the axles are made straight—the crank pins being inserted in the naves of the wheels. The bearings to which the connecting rods are attached are made with very large fillets in the corners, so as to strengthen the axle in that part, and to obviate side play in the connecting rod. In engines which have been in use for some time, however, there is generally a good deal of end play in the bearings of the axles themselves, and this slackness contributes to make the oscillation of the engine more violent; but this evil may be remedied by making the bearings with large corner fillets or with collars like the thrust bearing of a screw steamer.

Q. How are the bearings of the axles arranged?

A. The axles bear only against the top of the axle-boxes, which are generally of brass; but a plate extends underneath the bearing, to prevent sand from being thrown upon it. The upper part of the box in most engines has a reservoir of oil, which is supplied to the journal by tubes with siphon wicks. Stephenson uses cast iron axle boxes with brasses, and grease instead of oil; and the grease is fed upon the journal by the heat of the bearing melting it, whereby it is made to flow down through a hole in the brass.

Q. How are the eccentrics of a locomotive constructed?

A. Formerly the body of the eccentric was made of cast iron. In inside cylinder engines the eccentrics were set on the axle between the cranks, and they were put on in two pieces held together by bolts; but in straight axle engines the eccentrics were cast in a piece, and were secured on the shaft by means of a key. The eccentric, when in two pieces, was retained at its proper angle on the shaft by a pinching screw, which was provided with a jam nut to prevent it from working loose. A piece was left out of the eccentric in casting it to allow of the screw being inserted, and the void was afterwards filled by inserting a dovetailed piece of metal. Stephenson and Hawthorn left holes in their eccentrics on each side of the central arm, and they applied pinching screws in each of these holes. The method of fixing the eccentric to the shaft by a pinching screw was scarcely sufficiently substantial; and cases were perpetually occurring, when this method of attachment was adopted, of eccentrics shifting from their place. In the modern engines the eccentrics are forged on the axles.

Q. How are the eccentric straps constructed?

A. The eccentric hoops are generally of wrought iron or steel, as brass hoops are found liable to break. One half of the strap is forged with the rod, the other half being secured to it by bolts, nuts, and jam nuts. Pieces of brass are, in some cases, pinned within the steel hoop; but it appears to be preferable to put brasses within the hoop to encircle the eccentric, as in the case of any other bearing.

Q. What is the arrangement of the starting lever?

A. The starting lever travels between two iron segments, and can be fixed in any desired position. This is done by a small catch or bell-crank, jointed to the bottom of the handle at the end of the lever, and coming up by the side of the handle, but pressed out from it by a spring. The smaller arm of this bell-crank is jointed to a bolt, which shoots into notches, made in one of the segments between which the lever moves. By pressing the bell-crank against the handle of the lever the bolt is withdrawn, and the lever may be shifted to any other point, when, the spring being released, the bolt flies into the nearest notch.

Q. In what way does the starting handle act on the machinery of the engine to set it in motion?

A. Its whole action lies in raising or depressing the link of the link motion relatively with the valve rod. If the valve rod be attached to the middle of the link, the valve will derive no motion from it at all, and the engine will stop. If the attachment be slipped to one end of the link the engine will go ahead, and if slipped to the other end it will go astern. The starting handle merely achieves this change of position.

Q. Will you explain the operation of setting the valve of a locomotive?

A. In setting the valves of locomotives, place the crank in the position answerable to the end of the stroke of the piston, and draw a straight line, representing the centre line of the cylinder, through the centres of the crank shaft and crank pin. From the centre of the shaft describe a circle with the diameter equal to the throw of the valve, another circle to represent the crank shaft, and a third circle to represent the path of the crank pin. From the centre of the crank shaft draw a line perpendicular to the centre line of the cylinder and crank shaft, and draw another perpendicular at a distance from the first equal to the amount of the lap and the lead of the valve : the points in which this line intersects the circle of the eccentric are the points in which the centre of the eccentric should be placed for the forward and reverse motions. When the eccentric rod is attached directly to the valve, the radius of the eccentric, which precedes the crank in its revolution, forms with the crank an obtuse angle; but when, by the intervention of levers, the valve has a motion opposed to that of the eccentric rod, the angle contained by the crank and the radius of the eccentric must be acute, and the eccentric must follow the crank : in other words, with a direct attachment to the valve the eccentric is set *more* than one-fourth of a revolution in advance of the crank, and with an indirect attachment the eccentric is set *less* than one-fourth of a circle behind the crank. If the valve were without lead or lap the eccentric would be exactly one-fourth of a circle in advance of the crank or behind the crank, according to the nature of the valve connection. But as the valve would thus cover the port by the amount of the lap and lead, the eccentric must be set forward, so as to open the port to the extent of the lap and lead, and this is effected by the plan just described.

Q. In the event of the eccentrics slipping round upon the shaft, which you stated sometimes happens, is it necessary to perform the operation of setting the valve as you have just described it?

A. If the eccentrics shift upon the shaft, they may be easily refixed by setting the valve open the amount of the lead, setting the crank at the end of the stroke, and bringing round the eccentric upon the shaft until the eccentric rod gears with the valve. It would often be troublesome in practice to get access to the valve for the purpose of setting it, and this may be dispensed with if the amount of lap on the valve and the length of the eccentric rod be known. To this end, draw upon a board two straight lines at right angles to one another, and from their point of intersection as a centre describe two circles, one representing the circle of the eccentric, the other the crank shaft. Draw a straight line parallel to one of the diameters, and distant from it the amount of the lap and the lead. The points in which this parallel intersects the circle of the eccentric are the positions of the forward and backward eccentrics. Through these points draw straight lines from the centre of the circle, and mark the intersection of these lines with the circle of the crank shaft; measure with a pair of compasses the chord of the arc intercepted between either of these points, and the diameter which is at right angles with the crank, and the diameters being first marked on the shaft itself, then, by transferring with the compasses the distance found in the diagram, and marking the point, the eccentric may at any time be adjusted without difficulty.

Q. Will you describe the structure and arrangement of the feed pumps of locomotive engines?

A. The feed pumps of locomotives are generally made of brass, but the plungers are sometimes made of iron, and are generally attached to the piston cross head, though in some engines they are worked by rods attached to eyes on the eccentric hoops. There is a ball valve between the pump and the tender, and two usually in the pipe leading from the pump to the boiler. The ball valves are guided by four branches, which rise vertically, and join together at the top in a hemispherical form. The shocks of the ball against this cap have in some cases broken it after one week's work, from the top of the cage having been flat, and the branches not having had their junction at the top properly filleted. These valve guards are attached in different ways to the pipes; when one occurs at the junction of two pieces of pipe it has a flange, which along with the flanges of the pipes and that of the valve seat are held together by a union joint. It is sometimes formed with a thread at the under end, and screwed into the pipe. The balls are cast hollow to lessen the shock, as well as to save the metal. In some cases, where the feed pump plunger has been attached to the cross head, the piston rod has been bent by the strain; and that must in all cases occur, if the communication between the pump and boiler be closed when the engine is started, and there be no escape valve for the water.

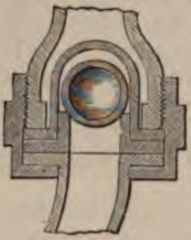


Fig. 98.—Ball Valve.

Q. Are none but ball valves used in the feed pump?

A. Spindle valves have in some cases been used instead of ball valves, but they are more subject to derangement; and the cage should be so made as to give the valve little lift, as shown in fig. 98. In all spindle valves opened and shut rapidly, it is advisable to have the lower surface conical, to take off the shock of the water; and a large lift of the valve should be prevented, else much of the water during the return stroke of the pump will flow out before the valve shuts. Giffard's injectors are now very generally employed to feed boilers instead of pumps.

Q. In what way are the valves of feed pumps arranged?

A. An example of such arrangement is given in fig. 99, which is a section of a locomotive feed pump of that kind which is worked off the eccentric. The plunger is a trunk plunger of short stroke. The water is drawn in through the lower ball valve and forced out through the upper one. There is a pet cock to let the steam out of the pump should any have leaked in, and to diminish the risks of such leakage it is a good practice to place another valve in the pipe which connects the pump with the boiler.

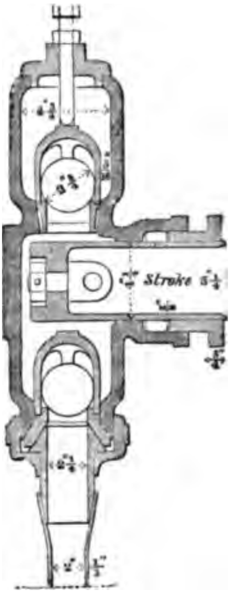


Fig. 99.—Section of Locomotive Feed Pump.

Q. At what part of the boiler is the feed water admitted?

A. The feed pipe of most locomotive engines enters the boiler near the bottom and about the middle of its length. In some engines the water is let in at the smoke box end of the boiler, a little below the water level; by this means the heat is more fully extracted from the escaping smoke. But the arrangement is of questionable applicability to engines of which the steam dome and steam pipe are at the smoke-box end, as in that case the entering cold water would condense the steam.

Q. Are all locomotives of modern construction provided with tenders to hold water and fuel?

A. Many engines are now made to carry the feed water over the boiler or beside or beneath it. These engines are called tank engines, and in the case of engines not fitted with injectors, donkey engines for feeding the boiler should in all cases be employed to work the feed pumps. The advantage of pumps over injectors is, that they enable hot water to be used for feeding the boiler instead of cold, whereby a saving of fuel will be effected. Injectors will not act in sending water into the boiler unless the jet of steam be condensed by the feed water, to do which its temperature should be under 90 degrees. But when pumps are used, a portion of the exhaust steam may be made to heat the feed water, which may consequently be sent into the boiler in a boiling state. However, the exhaust steam may be itself used as a jet to send water into the boiler in the manner of an injector under suitable arrangements.

Q. What would you consider such arrangements to be?

A. To explain them it is necessary to trace the principle upon which the injector operates. Steam taken from a boiler, it is clear, will not have sufficient pressure to force water into the same boiler, as it will not merely have the pressure of the steam resisting it, but the pressure of the column of water besides. If, however, a portion of the steam is condensed, it is transformed into a small jet of water moving with the velocity of the condensed steam, and it will have the dynamical energy due to that velocity, which it will be found corresponds to a hydrostatic head much more than sufficient to force its way into the boiler by gravity. If the pressure of the steam be very small—as will be the case if the steam educted by the engine is used—its force will be insufficient to send the water into the boiler, unless the steam is superheated. The superheated steam represents a higher head and greater velocity, and it will therefore act more powerfully in the injector.

Q. Will you explain the construction of locomotive wheels as made in this country?

A. The wheels of a locomotive are always made of malleable iron or steel. The driving wheels are made larger to increase the speed; the bearing wheels also are easier on the road when large. In goods engines the driving wheels are smaller than in the passenger engines, and are generally coupled together. Formerly wheels were sometimes made with cast-iron naves, and the spokes and rim of wrought iron. But in most modern wheels the nave is formed of the ends of the spokes welded together at the centre. The tires of railway wheels are now always made of steel, cast in an ingot, and a hole is punched in the middle, which is widened out until the tire can be rolled out without a weld. Sometimes corrugated disc wheels are formed of steel by casting, and twenty-two such wheels cast in one piece were shown at the Paris Exhibition of 1867.

Q. How do you find the length of bar necessary for forming a tire?

A. To find the proper length of bar requisite for the formation of a hoop of any given diameter, add the thickness of the bar to the required diameter, and the corresponding circumference in table of circumferences of circles is the length of the bar. If the iron be bent edgewise the breadth of the bar must be added to the diameter, for it is the thickness of the bar measured radially that is to be taken into consideration. In the tires of railway wheels, which have a flange on one edge, it is necessary to add not only the thickness of the tire, but also two-thirds of the depth of the flange. The tires, however, as above stated, are now rolled to the right size at once, in a special machine, whereby a weld is avoided. The ingot after being cast is hammered down into a piece like a cheese, which is then punched, next widened out, and finally rolled. The punch with which the perforation is effected is like the horn of an anvil.

Q. How are the tires attached to the wheels?

A. The tire is first heated to redness in a circular furnace. During the time it is getting hot, the iron wheel, turned to the right diameter, is bolted down upon a face or surface plate. The tire expands with the heat, and when at a cherry red, it is dropped over the wheel, for which it was previously too small, and it is also hastily bolted down to the surface plate. The whole mass is then quickly immersed by a swing crane in a tank of water five feet deep, and hauled up and down till nearly cold. The tire is attached to the rim with rivets having countersunk heads, and the wheel is then fixed on its axle.

Q. What is the most approved form of modern wheel for railway carriages?

A. On the whole, the disc wheel appears to be the best one; it is strongest, and acts least as a fan in raising the dust. Of disc wheels there are two approved varieties: one has the central part formed of wood, placed radially and surrounded by a steel hoop or tire; the other is a solid disc of steel, with the web concentrically corrugated, to give elasticity to the wheel and diminish the shock upon the railway. Wheels are sometimes made with a groove formed in the rim into which springs are introduced, which press upon an encircling hoop that rests on the rail, and the durability of the wheel and rail are thus increased from the increased elasticity imparted. But this plan has not yet been presented in such a form as to have come into permanent use. In all railways it is very desirable that the weight should be spread as evenly as possible over a large number of wheels. The rails should be kept smooth and fair; and both rails and wheels should be so made as to give elasticity. It cannot be said that any good method has yet been devised of accommodating the engine to curves; but radial axle-boxes or bogies may be employed.

Q. Are any precautions taken to prevent engines from being thrown off the rails by obstructions left upon the line?

A. In most engines a bar is strongly attached to the front of the carriage on each side, and projects perpendicularly downwards to within a short distance of the rail, to clear away stones or other obstructions that might occasion accidents if the engine ran over them. Originally nearly all trains had too little brake power, but a powerful steam brake acting on all the wheels of the train has now been introduced.

Q. What precautions are taken against accident from cattle straying upon the line?

A. In America and other countries, where in some districts the railways are unfenced, it is usual to put a great scoop, formed of strong bars, in front of the engine. This scoop, which is called a cow-catcher, receives any animal the train may overtake, and thus prevents the obstruction from throwing the engine off the rails.

CHAPTER VII.

STEAM NAVIGATION.

RESISTANCE OF VESSELS IN WATER.

Q. How do you determine the resistance encountered by a vessel moving in water?

A. The resistance experienced by vessels moving in water varies as the square of the velocity of their motion, or nearly so; and the power necessary to impart an increased velocity varies nearly as the cube of such increased velocity. To double the velocity of a steam vessel, therefore, will require four times the amount of tractive force, and as that quadrupled force must act through twice the distance in the same time, an engine capable of exerting eight times the original power will be required. This statement supposes that there is no difference of level between the water at the bow and the water at the stern. In the experiments on the French steamer 'Pelican,' the resistance was found to vary as the 2·28th power of the velocity. But the deviation from the recognised law was imputed to a difference in the level of the water at the bow and stern.

Q. In the case of a board moving in water in the manner of a paddle float, or in the case of moving water impinging on a stationary board, what will be the pressure produced by the impact?

A. The pressure produced upon a flat board, by water striking at right angles to the surface of the board, will be equal to the weight of a column of water having the surface struck as a base, and for its altitude twice the height due to the velocity with which the board moves through the water. If the board strike the water obliquely, the resistance will be less, but until lately no very reliable law has been discovered to determine its amount.

Q. Will not the resistance of a vessel in moving through the water be much less than that of a flat board of the area of the cross section?

A. It will be very much less, as is manifest from the comparatively small area of paddle board, and the small area of the circle described by the screw, relatively with the area of the immersed midship section of the vessel. The absolute speed of a vessel, with any given amount of power, will depend very much upon her shape.

Q. In what way is it that the shape of a vessel influences her resistance, since vessels of the same sectional area and of the same speed must manifestly put in motion a column of water of the same magnitude and with the same velocity?

A. A vessel will not strike the water with the same velocity when the bow lines are sharp as when they are otherwise; for a very sharp bow has the effect of enabling the vessel to move through a great distance, while the particles of water are moved aside but a small distance, or, in other words, it causes the velocity with which the water is moved to be very small relatively with the velocity of the vessel; and as the resistance increases rapidly with the velocity with which the water is moved, it is conceivable enough in what way a sharp bow may diminish the resistance.

Q. Is the whole power expended in the propulsion of a vessel consumed in moving aside the water to enable the vessel to pass?

A. By no means; only a portion, and in well-formed vessels only a small portion, of the power is thus consumed. In the majority of cases, the greater part of the power is expended in overcoming the friction of the water upon the bottom of the vessel; and the problem chiefly claiming consideration is, in what way we may diminish this friction.

Q. Does the resistance produced by this friction increase with the velocity?

A. It increases nearly as the square of the velocity. At two nautical miles per hour, the thrust necessary to overcome the friction varies as the 1·823 power of the velocity; and at eight nautical miles per hour, the thrust necessary to overcome the friction varies as the 1·713 power of the velocity. It is hardly proper, perhaps, to call this resistance by the name of friction; it is partly, perhaps mainly, due to the viscidity or adhesion of the water.

Q. Perhaps at high velocities this resistance may become less?

A. In former editions of this work such a result, it was stated, was highly probable, and recent experience with fast torpedo-boats has rather strengthened this anticipation. It may happen that at very high velocities the adhesion is to some extent overcome, so that the water is dragged off the vessel, and that the friction thereafter follows the law which obtains in the case of solid bodies. At all events, it has been found that the resistance, which at moderate velocities varies as the square, became greater with the speed until it exceeded the cube, and thereafter with still increasing velocities the resistance declined rather than increased. But this is no doubt in part imputable to the circumstance that light boats rise in the water at a high speed, and to some extent skim it, so that their immersed section becomes less.

Q. Up to such speeds as 10 miles an hour has any considerable departure been observed from the law that the frictional resistance of a body moving in water varies nearly as the square of the speed?

A. No.

Q. Does the amount of the friction per square foot vary with the nature of the surface?

A. Yes. Rough surfaces have more resistance than smooth.

Q. Is the friction per square foot of a ship's bottom greater at the bow than further astern?

A. It is greater at the bow. The result of Mr. Froude's experiments made with planks of different lengths and prepared with different kinds of surface is given in the following table:—

Friction of Surfaces.

Nature of surface	Length of surface or distance from cutwater											
	2 feet			8 feet			20 feet			50 feet		
	A	B	C	A	B	C	A	B	C	A	B	C
Varnish . . .	2·00	·41	·390	1·85	·325	·262	1·85	·278	·240	1·83	·250	·226
Paraffine .	1·95	·38	·370	1·94	·314	·260	1·93	·271	·237	,,	,,	,,
Tinfoil . . .	2·16	·30	·295	1·99	·278	·263	1·90	·262	·244	1·83	·246	·232
Calico . . .	1·93	·87	·725	1·92	·636	·504	1·89	·531	·447	1·87	·474	·423
Fine sand . .	2·00	·81	·690	2·00	·583	·450	2·00	·480	·384	2·06	·405	·337
Medium sand .	2·00	·90	·730	2·00	·625	·488	2·00	·534	·465	2·00	·488	·456
Coarse sand . .	2·00	1·10	·880	2·00	·714	·520	2·00	·588	·490	,,	,,	,,

A is the power of the speed to which the resistance is approximately proportional.

B is the resistance in pounds per square foot of a surface the length of which is that specified in the heading taken as the mean resistance of the whole length.

C is the resistance per square foot on unit of surface at the distance sternward from the cutwater specified in the heading.

Q. Will a vessel experience more resistance in moving in salt ater than in moving in fresh?

A. If the immersion be the same in both cases a vessel will xperience somewhat more resistance in moving in salt water than n moving in fresh, on account of the greater density of salt water; but as the flotation is proportionably greater in the salt water, the resistance will be the same with the same weight carried.

Q. Discarding for the present the subject of friction, and looking merely to the question of bow and stern resistance, in what manner should the hull of a vessel be formed so as to make these resistances a minimum?

A. The hull should be so formed that the water, instead of being driven away forcibly from the bow, is opened gradually, so that every particle of water may be moved aside slowly at first, and then faster, like the ball of a pendulum, until it reaches the position of the midship frame, at which point it will have come to a state of rest, and then again, like a returning pendulum, vibrate back in the same way until it comes to rest at the stern. It is not difficult to describe mechanically the line which the water should pursue. If an endless web of paper be put into uniform motion, and a pendulum carrying a pencil or brush be hung in front of it, then such pendulum will trace on the paper the prope water line of the ship, or the line which the water should pursu in order that no power may be lost except that which is lost i friction. It is found, however, in practice, that vessels formed wi water lines on this principle are not much superior to ordina vessels in the facility with which they pass through the water; ar this points to the conclusion that in ordinary vessels of good fo the amount of power consumed in overcoming the resistance d to the wave at the bow and the partial vacuity at the stern is so great as has heretofore been supposed, and that, in fact, th main resistance is that due to the friction. The power th consumed, however, should in part be recoverable under prop arrangements, except in so far as it may be transformed into he

EXPERIMENTS ON THE RESISTANCE OF VESSELS.

Q. Have experiments been made to determine the resista which steam vessels experience in moving through the water?

A. Experiments have been made both to determine the tive resistances of different classes of vessels, and also the ab resistances in pounds or tons. The first experiments made upon this subject were conducted by Messrs. Boulton and Watt, and they were numerous, long-continued, and carefully performed. These experiments were made upon paddle vessels, and the results of them were first communicated to the public in the present work.

Q. Will you recount the chief results of these experiments?

A. The purpose of the experiments was to establish a coefficient of performance, which with any given class of vessel would enable the speed which would be obtained with any given power to be readily predicted. This coefficient was obtained by multiplying the cube of the velocity of the vessels experimented upon, in miles per hour, by the sectional area of the immersed midship section in square feet, and dividing by the numbers of nominal horses power, and this coefficient was large in the proportion of the goodness of the shape of the vessel.

Q. How many of these early experiments were made altogether?

A. There were five different sets of experiments on five different classes of vessels. The first set of experiments was made in 1828, upon the vessels 'Caledonia,' 'Diana,' 'Eclipse,' 'Kinshead,' 'Moordyke,' and 'Eagle'—vessels of a similar form and all with square bilges and flat floors; and the result was to establish the number 925 as the coefficient of performance of such vessels. The second set of experiments was made upon the superior vessels 'Venus,' 'Swiftsure,' 'Dasher,' 'Arrow,' 'Spitfire,' 'Fury,' 'Albion,' 'Queen,' 'Dart,' 'Hawk,' 'Margaret,' and 'Hero'—all vessels having flat floors and round bilges, where the coefficient became 1,160. The third set of experiments was made upon the vessels 'Lightning,' 'Meteor,' 'James Watt,' 'Cinderella,' 'Navy Meteor,' 'Crocodile,' 'Watersprite,' 'Thetis,' 'Dolphin,' 'Wizard,' 'Escape,' and 'Dragon'—all vessels with rising floors and round bilges, and the coefficient of performance was found to be 1,430. The fourth set of experiments was made in 1834, upon the vessels 'Magnet,' 'Dart,' 'Eclipse,' 'Flamer,' 'Firefly,' 'Ferret,' and 'Monarch,' when the coefficient of performance was found to be 1,580. The fifth set of experiments was made upon the 'Red Rover,' 'City of Canterbury,' 'Herne,' 'Queen,' and 'Prince of Wales,' and in the case of those vessels the coefficient rose to 2,550. The velocity of any of these vessels, with any power or sectional area, may be ascertained by multiplying the coefficient of its class by the nominal horse-power, dividing by the sectional area in square feet, and extracting the cube root of the quotient, which will be the velocity in miles per hour; or the number of nominal horse-power requisite for the accomplishment of any required speed may be ascertained by multiplying the cube of the required velocity in miles per hour by the sectional area in square feet, and dividing by the coefficient: the quotient is the number of nominal horse-power requisite to realise the speed.

Q. Seeing, however, that the nominal power does not represent an invariable amount of dynamical efficiency, would it not be better to make the comparison with reference to the actual power?

A. Certainly; but in the case of these early experiments it was the nominal power that was taken. There was a known relation, however, between the actual and nominal power. In the whole of the experiments recited, except in the case of one or two of the last, the pressure of steam in the boiler varied between 2¼ lbs. and 4 lbs. per square inch, and the effective pressure on the piston varied between 11 lbs. and 13 lbs. per square inch, so that the average ratio of the nominal to the actual power may be easily computed; but it will be preferable to state the nominal power of some of the vessels, and their actual power as ascertained by experiment.

Q. Then state this.

A. Of the 'Eclipse,' the nominal power was 76, and the actual
power 144·4 horses; of the 'Arrow,' the nominal power was 60,
and the actual 119·5; 'Spitfire,' nominal 40, actual 64; 'Fury,'
nominal 40, actual 65·6; 'Albion,' nominal 80, actual 135·4
'Dart,' nominal 100, actual 152·4; 'Hawk,' nominal 40, actual 73
'Hero,' nominal 100, actual 171·4; 'Meteor,' nominal 100, actua
160; 'James Watt,' nominal 120, actual 204; 'Waterspri
nominal 76, actual 157·6; 'Dolphin,' nominal 140, actual 238
'Dragon,' nominal 80, actual 131; 'Magnet,' nominal 140, actu
238; 'Dart,' nominal 120, actual 237; 'Flamer,' nominal 1
actual 234; 'Firefly,' nominal 52, actual 86·6; 'Ferret,' nom
52, actual 88; 'Monarch,' nominal 200, actual 378. In the ca
swift vessels of modern construction, such as the 'Red R
'Herne,' 'Queen,' and 'Prince of Wales,' the coefficient app
be about 2,550; but in these vessels there is a still greater
of the actual over the nominal power than in the case of the
previously enumerated, and the increase in the coeff
consequent upon the increased pressure of the stean

boiler, as well as the superior form of the ship. The nominal power of the 'Red Rover,' 'Herne,' and 'City of Canterbury' is, in each case, 120 horses, but the actual power of the 'Red Rover' is 294, of the 'Herne' 354, and of the 'City of Canterbury' 306, and in some vessels the excess is still greater; so that with such variations it becomes necessary to adopt a coefficient derived from the introduction of the actual instead of the nominal power.

Q. What will be the average difference between the nominal and actual powers in the several classes of vessels you have mentioned and the respective coefficients when corrected for the actual power?

A. In the first class of vessels experimented upon, the actual power was about 1·6 times greater than the nominal power; in the second class, 1·67 times greater; in the third class, 1·7 times greater; and in the fourth, 1·96 times greater; while in such vessels as the 'Red Rover' and 'City of Canterbury' it was 2·65 times greater; so that if we adopt the actual instead of the nominal power in fixing the coefficients, we shall have 554 as the first coefficient, 694 as the second, 832 for the third, and 806 for the fourth, instead of 925, 1,160, 1,430, and 1,580, as previously specified; while for such vessels as the 'Red Rover,' 'Herne,' 'Queen,' and 'Prince of Wales,' we shall have 962 instead of 2,550. These smaller coefficients, then, express the relative merits of the different vessels without reference to any difference of efficacy in the engines, and it appears preferable, with such a variable excess of the actual over the nominal power, to employ them instead of those first referred to. From the circumstance of the third of the new coefficients being greater than the fourth, it appears that the superior result in the fourth set of experiments arose altogether from a greater excess of the actual over the nominal power.

Q. These experiments, you have already stated, were all made on paddle vessels. Have similar coefficients of performance been obtained in the case of screw vessels?

A. The coefficients of a great number of screw vessels have been obtained and recorded, but it would occupy too much time to enumerate them here. The coefficient of performance of the 'Fairy' is 464·8; of the 'Rattler' 676·8; and of the 'Frankfort' 792·3. This coefficient, however, refers to nautical and not to statute miles. If reduced to statute miles for the purpose of comparison with the previous experiments, the coefficients will respectively become 703, 1,033, and 1,212; which indicate that the performance of screw vessels is equal to the performance of paddle vessels, but some of the superiority of the result may be imputed to the superior size of the screw vessels. In modern practice the measure of distance is always the nautical mile, and the measure of power the actual power.

INFLUENCE OF THE SIZE OF VESSELS UPON THEIR SPEED.

Q. Will large vessels attain a greater speed than small, supposing each to be furnished with the same proportionate power?

A. It is well known that large vessels furnished with the same proportionate power will attain a greater speed than small vessels, as appears from the rule usual in yacht races of allowing a certain part of the distance to be run to vessels which are of inferior size. The velocity attained by a large vessel will be greater than the velocity attained by a small vessel of the same mould and the same proportionate power, in the proportion of the square roots of the linear dimensions of the vessels. This law discovered by the late Mr. Reech, and promulgated in the early editions of this work, was adopted by the late Mr. Froude as the basis of his researches, by which, by experiments on models, he was able to predict the performance of large vessels. He found that the resistance of a vessel is in the proportion of the cube of her linear dimension at speeds proportional to the square root of her linear dimension.

STRUCTURE AND OPERATION OF PADDLE WHEELS.

Q. Will you describe the configuration and mode of action of the paddle wheels in most general use?

A. Paddle vessels of every kind have very much gone out of late years. Yet there are two kinds of paddle wheels still in use, the one being the ordinary radial wheel, in which the floats are fixed on arms radiating from the centre; and the other the feathering wheel, in which each float is hung upon a centre, and is so governed by suitable mechanism as to be always kept in nearly the vertical position. In the radial wheel there is some loss of power from oblique action, whereas in the feathering wheel there is little or no loss from this cause; but in every kind of paddle there is a loss of power from the recession of the water from the float boards, or the *slip*, as it is commonly called; and this loss is the necessary condition of the resistance for the propulsion of the vessel being created in a fluid. The slip is expressed by the difference between the speed of the wheel and the speed of the vessel, and the larger this difference is the greater the loss of power from slip must be—the consumption of steam in the engine being proportionate to the velocity of the wheel, and the useful effect being proportionate to the speed of the ship.

Q. The resistance necessary for propulsion will not be situated at the circumference of the wheel?

A. In the feathering wheel, where every part of any one immerged float moves forward with about the same horizontal velocity, the pressure or resistance may be supposed to be concentrated in the centre of the float; whereas, in the common radial wheel this cannot be the case, for as the outer edge of the float moves in a larger circle, and therefore more rapidly than the edge nearest the centre of the wheel, the outer part of the float is the most effectual in propulsion. The point at which the outer and inner portions of the float just balance one another in propelling effect is called the *centre of pressure*; and if all the resistances were concentrated in this point, they would have the same effect as before in resisting the rotation of the wheel. The resistance upon any one moving float board totally immersed in the water will, when the vessel is at rest, obviously vary as the square of its distance from the centre of motion, the resistance of a fluid through a given distance varying with the square of the velocity; but, except when the wheel is sunk to the axle or altogether immersed in the water, it is impossible, under ordinary circumstances, for one float to be totally immersed without others being immersed partially, whereby the arc described by the extremity of the paddle arm will become greater than the arc described by the inner edge of the float; and consequently the resistance upon any part of the float will increase in a higher ratio than the square of its distance from the centre of motion—the position of the centre of pressure being at the same time correspondingly affected. In the feathering wheel the position of the centre of pressure of the entering and emerging floats is continually changing from the lower edge of the float—where it is when the float is entering or leaving the water—to the centre of the float, which is its position when the float is wholly immerged; but in the radial wheel the centre of pressure can never rise so high as the centre of the float.

Q. All this relates to the action of the paddle when the vessel is at rest: will you explain its action when the vessel is in motion?

A. When the wheel of a coach rolls along the ground, any point of its periphery describes in the air a curve which is termed a cycloid. Any point within the periphery traces a prolate or protracted cycloid, and any point exterior to the periphery traces a curtate or contracted cycloid—the prolate cycloid partaking more of the nature of a straight line, and the curtate cycloid more of the nature of a circle. The action of a paddle wheel in the water resembles in this respect that of the wheel of a carriage running along the ground: that point in the radius of the paddle of which the rotative speed is just equal to the velocity of the vessel will describe a cycloid; points nearer the centre, prolate cycloids, and points farther from the centre, curtate cycloids. The circle described by the point whose velocity equals the velocity of the ship is called the *rolling circle*, and the resistance due to the difference of velocity of the rolling circle and centre of pressure is that which operates in giving the necessary resistance to the float-boards for the propulsion of the vessel. The resistance upon any part of the float, therefore, in passing through any given distance, will vary as the square of its distance from the rolling circle, supposing the float to be totally immerged; but, taking into account the greater length of time during which the extremity of the paddle acts, whereby the resistance will be made greater, we shall not err far in estimating the resistance per unit of motion upon any point at the third power of its distance from the rolling circle in the case of light immersions, and the 2·5 power in the case of deep immersions.

Q. Should the floats in feathering wheels enter and leave the water vertically?

A. The floats should be so governed by the central crank or eccentric, that the entering and emerging floats have a direction intermediate between a radius and a vertical line.

Q. Can you give any practical rules for proportioning paddle wheels?

A. A common rule for the pitch of the floats in radial wheels is to allow one float for every foot of diameter of the wheel, and in feathering wheels the floats are placed about twice as far apart as in radial. To find the proper area of a single float: Divide the number of actual horses power of both engines by the diameter of the wheel in feet; the quotient is the area of one paddle-board in square feet proper for sea-going vessels, and the area multiplied by 0·6 will give the length of the float in feet. In very sharp vessels, which offer less resistance in passing through the water, the area of paddle-board is usually one-fourth less than the above proportion, and the proper length of the float may in such case be found by multiplying the area by 0·7. In sea-going vessels with radial wheels about four floats are usually immersed, and in river steamers less than this. There is more slip in the latter case, but there is also more engine power exerted in the propulsion of the ship, from the greater speed of engine thus rendered possible.

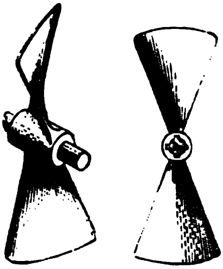
Q. Then is it beneficial to use small floats?

A. Quite the contrary. If, to permit a greater speed of the engine, the floats be diminished in area instead of being raised out of the water, no appreciable accession to the speed of the vessel will be obtained; whereas there will be an increased speed of vessel if the accelerated speed of the engine be caused by diminishing the diameter of the wheels. In vessels intended to be very fast, therefore, it is expedient to make the wheels small, so as to enable the engine to work with a high velocity; and it is expedient to make such wheels of the feathering kind, to obviate loss of power from oblique action. In no wheel must the rolling circle fall below the water line, else the entering and emerging floats will carry masses of water before them. The slip is usually equal to about one-fourth of the velocity of the centre of pressure in well-proportioned wheels; but it is desirable to have the slip as small as is possible consistently with the observance of other necessary conditions. The speed of the engine and also the speed of the vessel being fixed, the diameter of the rolling circle becomes at once ascertainable, and adding to this the slip, we have the diameter of the wheel.

CONFIGURATION AND ACTION OF THE SCREW.

Q. Will you describe the configuration and mode of action of the screw propeller?

A. The form of screw propeller finally adopted in the 'Rattler,' after numerous experiments to determine the best proportions, is represented in figs. 100 and 101; fig. 100 being a perspective view, and fig. 101 an end view, or view such as is seen when looking upon the end of the shaft; but it is found better to narrow the blade at its outer part, so as to bring it to somewhat of a shovel form. The screw here represented is one with two arms or blades. But some screws have three arms, some four, and some six. The screw, on being put into revolution by the engine, preserves a spiral path in the water, in which it draws itself forward in the same way as a screw nail does when turned round in a piece of wood, whereas the paddle wheel more resembles the action of a cog wheel working in a rack.



Figs. 100 and 101.—Ordinary form of Screw Propeller.

Q. But the screw of a steam vessel has no resemblance to a screw nail?

A. It has, in fact, a very close resemblance, if you suppose only a very short piece of the screw nail to be employed, and if you suppose, moreover, the thread of the screw to be cut nearly into the centre to prevent the wood from stripping. The original screw propellers were made with several convolutions of screw, but it was found advantageous to shorten them, until they are now only made about one-sixth of a convolution in length.

Q. And the pitch you have already explained to be the distance in the line of the shaft from one convolution to the next, supposing the screw to consist of one or more convolutions?

A. Yes, that is what is meant by the pitch. If a thread be wound upon a cylinder with an equal distance between the convolutions, it will trace a screw of a uniform pitch; and if the thread be wound upon the cylinder with an increasing distance between each convolution, it will trace a screw of an increasing pitch. But two or more threads may be wound upon the cylinder at the same time, instead of a single thread. If two threads be wound upon it they will trace a double-threaded screw; if three threads be wound upon it they will trace a treble-threaded screw; and so of any other number. Now if the thread be supposed to be raised up into a very deep and thin spiral feather, and the cylinder be supposed to become very small, like the newel of a spiral stair, then a screw will be obtained of the kind proper for propelling vessels, except that only a very short piece of such screw must be employed. Whatever be the number of threads wound upon a cylinder, if the cylinder be cut across all the threads will be cut. A slice cut out of the cylinder will therefore contain a piece of each thread. But the threads, in the case of a screw propeller, answer to the arms, so that in every screw propeller the number of threads entering into the composition of the screw will be the same as the number of arms. An ordinary screw with two blades is a short piece of a screw of two threads.

Q. In what part of the ship is the screw usually placed?

A. In that part of the run of the ship called the dead wood, which is a thin and unused part of the vessel just in advance of the rudder. The usual arrangement is shown in fig. 102, which represents the application to a vessel of a species of screw which has the arms bent backwards, to counteract the centrifugal motion given to the water when there is a considerable amount of slip.

Q. How is the slip in a screw vessel determined?

A. By comparing the actual speed of the vessel with the speed due to the pitch and number of revolutions of the screw, or, what is the same thing, the speed which the vessel would attain if the screw worked in a solid nut. The difference between the actual speed and this hypothetical speed is the slip.

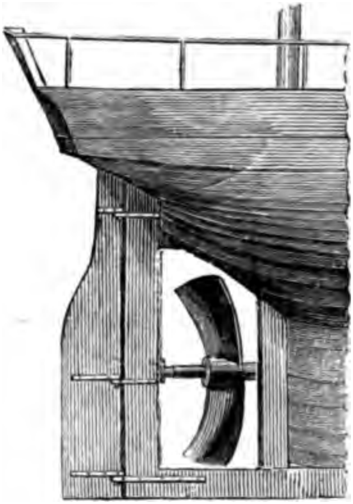


Fig. 102.—Hodgson's Screw Propeller.

Q. In well-formed screw propellers what is the amount of slip found to be?

A. If the screw be properly proportioned to the resistance that the vessel has to overcome, the slip will not be more than 10 per cent., but in some cases it amounts to 30 per cent., or even more than this. In other cases, however, the slip is nothing at all, and even less than nothing; or, in other words, the vessel passes through the water with a greater velocity than if the screw were working in a solid nut.

Q. Then it must be by the aid of the wind or some other extraneous force?

A. No; by the action of the screw alone.

Q. But how is such a result possible?

A. It appears to be partly owing to the centrifugal action of the screw, which interposes a film or wedge of water between the screw itself and the water on which the screw reacts. This negative slip, as it is called, chiefly occurs when the pitch of the screw is less than its diameter, and when, consequently, the velocity of rotation is greater than if a coarser pitch had been employed. There is, moreover, in all vessels passing through the water with any considerable velocity, a current of water following the vessel, in which current the screw will revolve; and the phenomenon of negative slip is imputable mainly to the existence of this current, which contains much of the *vis viva* generated by the engine.

COMPARATIVE ADVANTAGES OF PADDLE AND SCREW VESSELS.

Q. Whether do you consider paddle or screw vessels to be on the whole the more advantageous?

A. That is a question which can only receive a qualified answer. In some cases the use of paddles is indispensable, as, for example, in the case of river vessels of a limited draught of water, where it would not be possible to get sufficient depth below the water surface to enable a screw of a proper diameter to be got in.

Q. But how does the matter stand in the case of ocean vessels?

A. This question is practically answered by the almost universal supersession of paddle vessels by screws. But in the experiments instituted when the screw was being introduced, it was found in the case of small vessels that paddle vessels fitted with the ordinary radial wheels, and screw vessels fitted with the ordinary screw, were about equally efficient in calms and in fair or beam winds with light and medium immersions. If the vessels were loaded deeply, however, as vessels starting on a long voyage and carrying much coal must almost necessarily be, then the screw had an advantage, since the screw acts in its best manner when deeply immersed, and the paddles in their worst. When a screw and paddle vessel, however, of the same model and power were set to encounter head winds, the paddle vessel, it was found, had in all cases an advantage, not in speed, but in economy of fuel. For whereas in a paddle vessel, when her progress is resisted, the speed of the engine diminishes nearly in the proportion of the diminished speed of ship, it happens that in a screw vessel this is not so—at least to an equal extent—but the engines work at nearly the same rate of speed as if no increase of resistance ha been encountered by the ship. It follows from this circumstance, that whereas in paddle vessels the consumption of steam, and therefore of fuel, per hour is materially diminished when head winds occur, in screw vessels a similar diminution in the consumption of steam and fuel does not take place.

Q. But perhaps under such circumstances the speed of the screw vessel would be the greater of the two?

A. No; the speed of the two vessels would be the same, unless the strength of the head wind were so great as to bring the vessels nearly to a state of rest, and on that supposition the screw vessel would have the advantage. Such cases occur very rarely in practice; and in the case of the ordinary resistances imposed by head winds, the speed of the screw and paddle vessel will be the same, but the screw vessel will consume most coals.

Q. What is the cause of this peculiarity?

A. The cause is that, when the screw is so proportioned in its ength as to be most suitable for propelling vessels in calms, it is oo short to be suitable for propelling vessels which encounter a very heavy resistance. It follows, therefore, that if it is prevented from pursuing its spiral course in the water, it will displace the water to a certain extent laterally, in the manner it does if the engine be set on when the vessel is at anchor; and a part of the engine power is thus wasted in producing a useless disturbance of the water, which in paddle vessels is not expended at all.

Q. If a screw and paddle vessel of the same mould and power be tied stern to stern, will not the screw vessel preponderate and tow the paddle vessel astern against the whole force of her engines?

A. Yes, that will be so.

Q. And seeing that the vessels are of the same mould and power, so that neither can derive an advantage from a variation in that condition, does not the preponderance of the screw vessel show that the screw must be the more powerful propeller?

A. No, it does not.

Q. Seeing that the vessels are the same in all respects except as regards the propellers, and that one of them exhibits a superiority, does not this circumstance show that one propeller must be more powerful than the other?

A. That does not follow necessarily, nor is it the fact in this particular case. All steam vessels, when set in motion, will force themselves forward with an amount of thrust which, setting aside the loss from friction and from other causes, will just balance the pressure on the pistons. In a paddle vessel, as has already been explained, it is easy to tell the tractive force exerted at the centre of pressure of the paddle wheels, when the pressure urging the pistons, the dimensions of the wheels, and the speed of the vessel are known; and that force, whatever be its amount, must always continue the same with any constant pressure on the pistons. In a screw vessel the same law applies, so that with any given pressure on the pistons and discarding the consideration of friction, it will follow that whatever be the thrust exerted by a paddle or a screw vessel, it must remain uniform whether the vessel is in motion or at rest, and whether moving at a high or a low velocity through the water. Now, to achieve an equal speed during calms in two vessels of the same model, there must be the same amount of propelling thrust in each; and this thrust, whatever be its amount, cannot afterwards vary if a uniform pressure of steam be maintained. The thrusts, therefore, caused by their respective propelling instruments, when a screw and paddle vessel are tied stern to stern, must be the same as at other times; and as at other times those thrusts are equal, so must they be when the vessels are set in the antagonism supposed.

Q. How comes it then that the screw vessel preponderates?

A. Not by virtue of a larger thrust exerted by the screw in pressing forward the shaft and with it the vessel, but by the gravitation against the stern of the wave of water which the screw raises by its rapid rotation. This wave will only be raised very high when the progress of the vessel through the water is nearly arrested, at which time the centrifugal action of the screw is very great; and the vessel under such circumstances is forced forward partly by the thrust of the screw, and partly by the hydrostatic pressure of the protuberance of water which the centrifugal action of the screw raises up at the stern.

Q. Can you state any facts in corroboration of this view?

A. The screw vessel will not preponderate if a screw and paddle vessel be tied bow to bow and the engines of each be then reversed. In some screw vessels the amount of thrust actually exerted by the screw, under all its varying circumstances, has been ascertained by the application of a dynamometer to the end of the shaft. By this instrument—which is formed by a combination of levers like a weighing machine for carts—a thrust or pressure of several tons can be measured by the application of a small weight; and it has been found, by repeated experiments with the dynamometer, that the thrust of the screw in a screw vessel when towing a paddle vessel against the whole force of her engines, is just the same as it is when the two vessels are maintaining an equal speed in calms. The preponderance of the screw vessel must, therefore, be imputable to some other agency than to a superior thrust of the screw, which is found by experiment not to exist.

Q. Has the dynamometer been applied to paddle vessels?

A. It has not been applied to the vessels themselves, as in the case of screw vessels, but it has been employed on shore to ascertain the amount of tractive force that a paddle vessel can exert on a rope. In a screw vessel fitted with a dynamometer within the ship, the thrust shown by it will be less than that shown by a dynamometer on shore, to which the vessel is attached by a rope.

Q. Why is this?

A. Because the shore dynamometer will show not only the thrust of the screw but also the gravitation of the wave of water against the stern which the screw generates by its centrifugal action.

Q. Have any experiments been made to determine the comparative performances of screw and paddle vessels at sea?

A. Yes, numerous experiments; of which the best known are probably those made on the screw steamer 'Rattler' and the paddle steamer 'Alecto,' each vessel of the same model, size, and power—each vessel being of about 800 tons burden and 200 horses power. Subsequently another set of experiments with the same object was made with the 'Niger' screw steamer and the 'Basilisk' paddle steamer, both vessels being of about 1,000 tons burden and 400 horses power. The general results which were obtained in the course of these experiments are those which have been already recited.

Q. Will you recapitulate some of the main incidents of these trials?

A. I may first state some of the chief dimensions of the vessels. The 'Rattler' is 176 feet 6 inches long, 32 feet 8½ inches broad, 888 tons burden, 200 horses power, and has an area of immersed midship section of 380 square feet at a draught of water of 11 feet 5½ inches. The 'Alecto' is of the same dimensions in every respect, except that she is only of 800 tons burden, the difference in this particular being wholly owing to the 'Rattler' having been drawn out about 15 feet at the stern, to leave abundant room for the application of the screw. The 'Rattler' was fitted with a dynamometer, which enabled the actual propelling thrust of the screw shaft to be measured; and the amount of this thrust, multiplied by the distance through which the vessel passed in a given time, would determine the amount of power actually utilised in propelling the ship. Both vessels were fitted with indicators applied to the cylinders, so as to determine the amount of power exerted by the engines.

Q. How many trials of the vessels were made on this occasion?

A. Twelve trials in all; but I need not refer to those in which similar or identical results were only repeated. The first trial was made under steam only; the weather was calm and the water smooth. At 54 minutes past 4 in the morning both vessels left the Nore, and at 30½ minutes past 2 the 'Rattler' stopped her engines in Yarmouth Roads, where in 20½ minutes afterwards she was joined by the 'Alecto.' The mean speed achieved by the 'Rattler' during this trial was 9·2 knots per hour; the mean speed of the 'Alecto' was 8·8 knots per hour. The slip of the screw was 10·2 per cent. The actual power exerted by the engines, as shown by the indicator, was in the case of the 'Rattler' 334·6 horses, and in the case of the 'Alecto' 281·2 horses; being a difference of 53·4 horses in favour of the 'Rattler.' The forward thrust upon the screw shaft was 3 tons 17 cwt. 3 qrs. and 14 lbs. The horse power of the shaft—or power actually utilised—ascertained by multiplying the thrust in pounds by the space passed through by the vessel in feet per minute, and dividing by 33,000, was 247·8 horses power. This makes the ratio of the shaft to the engine power as 1 to 1·3, or, in other words, it shows that the amount of engine power utilised in propulsion was 77 per cent. In a subsequent trial made with the vessels running before the wind, but with no sails set and the masts struck, the speed realised by the 'Rattler' was 10 knots per hour. The slip of the screw was 11·2 per cent. The actual power exerted by the engines of the 'Rattler' was 368·8 horses. The actual power exerted by the engines of the 'Alecto' was 291·7 horses. The thrust of the shaft was equal to a weight of 4 tons 4 cwt. 1 qr. 1 lb. The horse-power of the shaft was 290·2 horses, and the ratio of the shaft to the engine power was 1 to 1·2. Here, therefore, the amount of the engine power utilised was 84 per cent.

Q. If in any screw vessel the power of the engine be diminished by shutting off the steam or otherwise, you will then have a larger screw relatively with the power of the engine than before?

A. Yes.

Q. Was any experiment made to ascertain the effect of this modification?

A. There was; but the result was not found to be better than before. The experiment was made by shutting off the steam from the engines of the 'Rattler,' until the number of strokes was reduced to 17 in the minute. The actual power was then 126·7 horses; thrust upon the shaft 2 tons 2 cwt. 3 qrs. 14 lbs.; horsepower of shaft 88·4 horses; ratio of shaft to engine power 1 to 1·4; slip of the screw 18·7 per cent. In this experiment the power utilised was 71 per cent.

Q. Was any experiment made to determine the relative performances in head winds?

A. The trial in which this relation was best determined lasted for seven hours, and was made against a strong head wind and heavy head sea. The speed of the 'Rattler' by patent log was 4·2 knots; and at the conclusion of the trial the 'Alecto' had the advantage by about half a mile. Owing to an accidental injury to the indicator, the power exerted by the engines of the 'Rattler' in this trial could not be ascertained; but judging from the power exerted in other experiments with the same number of revolutions, it appears probable that the power actually exerted by the 'Rattler' was about 300 horses. The number of strokes per minute made by the engines of the 'Rattler' was 22, whereas in the 'Alecto' the number of strokes per minute was only 12; so that while the engines of the 'Alecto' were reduced, by the resistance occasioned by a strong head wind, to nearly half their usual speed, the engines of the 'Rattler' were only lessened about one-twelfth of their usual speed. The mean thrust upon the screw shaft during this experiment was 4 tons 7 cwt. 0 qr. 16 lbs. The horse-power of the shaft was 125·9 horses, and the slip of the screw was 56 per cent. Taking the power actually exerted by the 'Rattler' at 300 horses, the power utilised in this experiment is only 42 per cent.

Q. What are the dimensions of the screw in the 'Rattler?'

A. Diameter 10 feet, length 1 foot 3 inches, pitch 11 feet. The foregoing experiments show that with a larger screw a better average performance would be obtained. The best result arrived at was when the vessel was somewhat assisted by the wind, which is equivalent to a reduction of the resistance of the hull, or to a smaller hull, which is only another expression for a larger proportionate screw.

Q. When you speak of a larger screw, what increase of dimension do you mean to express?

A. An increase of the diameter. The amount of reacting power of the screw upon the water is not measured by the number of square feet of surface of the arms, but by the area of the disc or circle in which the screw revolves. The diameter of the screw of the 'Rattler' being 10 feet, the area of its disc is 78·5 square feet; and with the amount of thrust already mentioned as existing in the first experiment, viz. 8,722 lbs., the reacting pressure on each square foot of the screw's disc will be 108½ lbs. The immersed midship section being 380 square feet, this is equivalent to 23 lbs. per square foot of immersed midship section at a speed of 9·2 knots per hour.

Q. In smaller vessels of similar form, will the resistance per square foot of midship section be more than this?

A. It will be considerably more. In the 'Pelican,' a vessel of 109¾ square feet of midship section, I estimate the resistance per square foot of midship section at 30 lbs., when the speed of the vessel is 9·7 knots per hour. In the 'Minx,' with an immersed midship section of 82 square feet, the resistance per square foot of immersed midship section was found by the dynamometer to be 41 lbs. at a speed of 8½ knots; and in the 'Dwarf,' a vessel with 60 square feet of midship section, I estimate the resistance per square foot of midship section at 46 lbs. at a speed of 9 knots per hour, which is just double the resistance per square foot of the 'Rattler.' The diameter of the screw of the 'Minx' is 4½ feet, so that the area of its disc is 15·9 square feet, and the area of immersed midship section is about 5 times greater than that of the screw's disc. The diameter of the screw of the 'Dwarf' is 5 feet 8 inches, so that the area of its disc is 25·22 square feet, and the area of immersed midship section is 2·4 times greater than that of the screw's disc. The pressure per square foot of the screw's disc is 214 lbs. in the case of the 'Minx,' and 109½ lbs. in the case of the 'Dwarf.'

Q. From the greater proportionate resistance of small vessels, will not they require larger proportionate screws than large vessels?

A. They will.

Q. Is there any ready means of predicting what the amount of thrust of a screw will be?

A. When we know the amount of pressure on the pistons, and the velocity of their motion relatively with the velocity of advance made by the screw, supposing it to work in a solid nut, it is easy to tell what the thrust of the screw would be if it were cleared of the effects of friction and other irregular sources of disturbance. The thrust, in fact, would be at once found by the principle of virtual velocities; and if we take this theoretical thrust and diminish it by one-fourth to compensate for friction and lateral slip, we shall have a near approximation to the amount of thrust that will be actually exerted.[1]

COMPARATIVE ADVANTAGES OF SCREWS OF DIFFERENT KINDS.

Q. What species of screw do you consider the best?

A. In cases in which a large diameter of screw can be employed, the ordinary screw or helix seems to be as effective as any other, and it is the most easily constructed. If, however, the screw is restricted in diameter, or if the vessel is required to tow, or will have to encounter habitually strong head winds, it will be preferable to employ a screw with an increasing pitch, and also of such other configuration that it will recover from the water some portion of the power that has been expended in propulsion.

Q. How can this be done?

A. There are screws which are intended to accomplish this object already in actual use. When there is much slip a centrifugal velocity is given to the water, and the screw, indeed, if the engine be set on when the vessel is at rest, acts very much as a centrifugal fan would do if placed in the same situation. The water projected outwards by the centrifugal force escapes in the line of least resistance, which is to the surface; and if there be a high column of water over the screw, or, in other words, if the screw is deeply immersed, then the centrifugal action is resisted to a greater extent, and there will be less slip produced. The easiest expedient, therefore, for obviating loss by slip is to sink the screw deeply in the water; but as there are obvious limits to the application of this remedy, the next best device is to recover and render available for propulsion some part of the power which has been expended in giving motion to the water. It is reckoned that in long vessels the larger part of the engine power is expended in giving motion to the water, and the screw by working in this current will recover a part of the power so expended.

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[1] See *Treatise on the Screw Propeller*, by John Bourne, C.E.

Q. But you said there are some kinds of screws which profess to accomplish this?

A. There are screws which profess to counteract the centrifugal velocity given to the water by imparting to it an equal centripetal force, the consequence of which will be, that the water projected backward by the screw, instead of taking the conical form, will take the form of a cylinder. One of these forms of screw is that patented by the Earl of Dundonald in 1843, and which is represented in fig. 103. Another is the form of screw already represented in fig. 102, and which was patented by Mr. Hodgson in 1844. Mr. Hodgson bends the arms of his propellers backward, not into the form of a triangle, but into the form of a parabola, to the end that the impact of the screw on the particles of the water may cause them to converge to a focus, as the rays of light would do in a parabolic reflector. But this particular configuration is not important, seeing that the same convergence which is given to the particles of the water, with a screw of uniform pitch bent back into the form of a parabola, will be given with a screw bent back into the form of a triangle, if the pitch be suitably varied between the centre and the circumference.

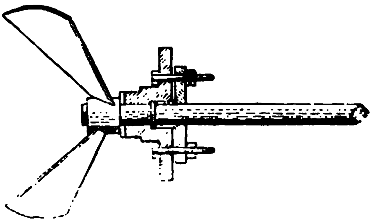
Fig. 103.- The Earl of Dundonald's Propeller

Q. Then the pitch may be varied in two ways?

A. Yes; a screw may have a pitch increasing in the direction of the length, as would happen in the case of a spiral stair, if every successive step in the ascent was thicker than the one below it; or it may increase from the centre to the circumference, as would happen in the case of a spiral stair, if every step were thinner at the centre of the tower than at its outer wall. When the pitch of a screw increases in the direction of its length, the leading edge of the screw enters the water without shock or impact, as the advance of the leading edge per revolution will not be greater than the advance of the vessel. When the pitch of a screw increases in the direction of its diameter, the central part of the screw will advance with only the same velocity as the vessel, so that it cannot communicate any centrifugal velocity to the vessel; and the whole slip, as well as the whole propelling pressure, will occur at the outer part of the screw blades.

Q. Is there any advantage derived from these forms of screws?

A. Not any, as the water in being forced backward flows in from the circumference in front of the screw, and Griffith has found it advisable therefore to bend the ends of the blades forward instead of backward, and to make the ends quite narrow.

Q. What other kinds of screw are there?

A. There is the corrugated screw, the arms of which are corrugated, so, as it were, to gear with the water during its revolution, and thereby prevent it from acquiring a centrifugal velocity. Then there is Griffith's screw, which has a large ball at its centre. There is also Mangin's screw, which consists substantially of two narrow screws, set one before the other on the same shaft, with a space between, and there are numerous new screws constantly appearing which are only reproductions of old ideas.

Q. What is the nature of Beattie's screw?

A. Beattie's screw is an arrangement of the screw propeller whereby it is projected beyond the rudder, and the main object of the arrangement is to take away the vibratory motion at the stern —an intention which it accomplishes in practice. There is an oval eye in the rudder, to permit the screw shaft to pass through it, as shown in fig. 104.

Q. When the diameter of the cylinder of water projected backward by a screw and the force urging it into motion are known, may not the velocity it will acquire be approximately determined?

A. That will not be very difficult; and I will take for illustration the case of the 'Minx,' already referred to, which will show how such a computation is to be conducted. The speed of this vessel, in one of the experiments made with her, was 8·445 knots; the number of revolutions of the screw per minute 231·32; and the pressure on each square foot of area of the screw's disc 214 lbs. If a knot be taken to be 6075·6 feet, then the distance advanced by the vessel, when the speed is 8·445 knots, will be 3·7 feet per revolution, and this advance will be made in about ·26 of a second of time. Now the distance which a body will fall by gravity in ·26 of a second is 1·087 feet; and a weight of 214 lbs. put into motion by gravity, or by a pressure of 214 lbs., would, therefore, acquire a velocity of 1·087 feet during the time one revolution of the screw is being performed. The weight to be moved, however, is 3·7 cubic

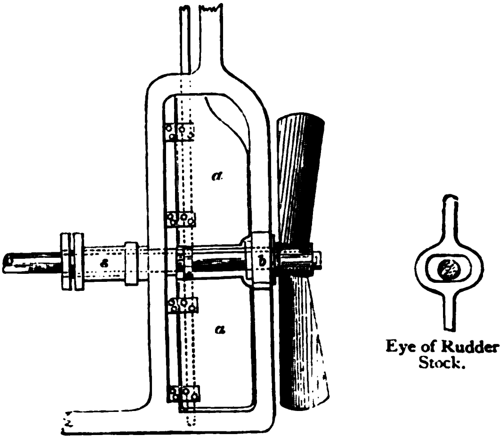

Fig. 104.—Beattie's arrangement of Screw Propeller. *a a*, the rudder; *s*, the shaft; *b*, boss for supporting shaft.

feet of water, that being the new water seized by the screw each revolution for every square foot of surface in the screw's disc; and 3·7 cubic feet of water weigh 231·5 lbs., so that the urging force of 214 lbs. is somewhat less than the force of gravity, and the velocity of motion communicated to the water will be somewhat under 1·087 feet per revolution, or we may say it will be in round numbers 1 foot per revolution. This, added to the progress of the vessel, will make the distance advanced by the screw through the water 4·7 feet per revolution, leaving the difference between this and the pitch, namely 1·13 feet, to be accounted for on the supposition that the screw blades had broken laterally through the water to that extent. It would be proper to apply some correction to this computation, which would represent the increased resistance due to the immersion of the screw in the water; for a column of water cannot be moved in the direction of its axis beneath the surface without giving motion to the superincumbent water, and the inertia of this superincumbent water must, therefore, be taken into the account. In the experiment upon the 'Minx,' the depth of this superincumbent column was but small. The total amount of the slip was 36·53 per cent.; and there will not be much error in setting down about one-half of this as due to the recession of the water in the direction of the vessel's track, and the other half as due to the lateral penetration of the screw-blades.

Q. Is it not important to make the stern of screw vessels very fine, with the view of diminishing the slip, and increasing the speed?

A. It is most important. The 'Rifleman,' a vessel of 486 tons, had originally engines of 200 horses power, which propelled her at a speed of 8 knots an hour. The 'Teazer, a vessel of 296 tons, had originally engines of 100 horses power, which propelled her at a speed of 6½ knots an hour. The engines of the 'Teazer' were subsequently transferred to the 'Rifleman,' and new engines of 40 horse-power were put into the 'Teazer.' Both vessels were simultaneously sharpened at the stern, and the result was that the 100-horse engines drove the 'Rifleman,' when sharpened, as fast as she had previously been driven by the 200-horse engines; and the 40-horse engines drove the 'Teazer,' when sharpened, a knot an hour faster than she had previously been driven by the 100-horse engines. The immersion of both vessels was kept unchanged in each case; and the 100-horse engines of the 'Teazer,' when transferred to the 'Rifleman,' drove that vessel, after she had been sharpened, 2 knots an hour faster than they had previously driven a vessel not much more than half the size. These are important facts for everyone to be acquainted with who is interested in the success of screw vessels, and who seeks to obtain the maximum of efficiency with the minimum of expense.[1]

PROPORTIONS OF SCREWS.

Q. In fixing upon the proportions of a screw proper to propel any given vessel, how would you proceed?

A. I would first compute the probable resistance of the vessel, and I would be able to find the relative resistances of the screw and hull. In nearly every case it is advisable to make the screw as large in diameter as possible. The larger the screw is, the greater will be the efficiency of the engine in propelling the vessel, as less of its power will be expended in giving velocity to the water; the larger also will be the ratio of the pitch to the diameter which produces a maximum effect; and the smaller will be the length of the screw or the fraction of a convolution to produce a maximum effect.

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[1] See *Treatise on the Screw Propeller*, by John Bourne, C.E.

Q. Will you illustrate this doctrine by a practical example?

A. The French screw steamer 'Pelican' was fitted successively with two screws of four blades, but the diameter of the first screw was 98·42 inches, and the diameter of the second 54 inches. If the efficiency of the first screw be represented by 1, that of the second screw will be represented by ·823, or, in other words, if the first screw would give a speed of 10 knots, the second would give little more than 8. The most advantageous ratio of pitch to diameter was found to be 2·2 in the case of the large screw, and 1·384 in the case of the small. The fraction of a convolution which was found to be most advantageous was ·281 in the case of the large screw, and ·450 in the case of the small screw.

Q. Were screws of four blades found to be more efficient than screws with two?

A. They were found to have less slip, but not to be more efficient, the increased slip in those of two blades being balanced by the increased friction in those of four. Screws of two blades, to secure a maximum efficiency, must have a finer pitch than screws of four.

Q. Are the proportions found to be most suitable in the case of the 'Pelican' applicable to the screws of other vessels?

A. Only to those which have the same relative resistance of screw and hull. Taking the relative resistance to be the area of immersed midship section, divided by the square of the screw's diameter, it will in the case of the 'Rattler' be $\frac{380}{100}$ or 3·8. From the experiments made by MM. Bourgois and Moll on the screw steamer 'Pelican,' they have deduced the proportions of screws proper for all other classes of vessels, whether the screws are of two, four, or six blades.

Q. Will you specify the nature of their deductions?

A. I will first enumerate those which bear upon screws with two blades. When the relative resistance is 5·5, the ratio of pitch to diameter should be 1·006, and the fraction of the pitch or proportion of one entire convolution should be 0·454. When the relative resistance is 5, the ratio of pitch to diameter should be 1·069 and fraction of pitch 0·428; relative resistance 4·5, pitch 1·135, fraction 0·402; relative resistance 4, pitch 1·205, fraction 0·378; relative resistance 3·5, pitch 1·279, fraction 0·355; relative resistance 3, pitch 1·357, fraction 0·334; relative resistance 2·5, pitch 1·450, fraction 0·313; relative resistance 2, pitch 1·560, fraction 0·294; relative resistance 1·5, pitch 1·682, fraction 0·275. The relative resistance of 4 is that which is usual in an auxiliary line-of-battle ship, 3·5 in an auxiliary frigate, 3 in a high-speed line-of-battle ship, 2·5 in a high-speed frigate, 2 in a high-speed corvette, and 1·5 in a high-speed despatch boat.

Q. What are the corresponding proportions of screws of four blades?

A. The ratios of the pitches to the diameter being for each of the relative resistances enumerated above 1·342, 1·425, 1·513, 1·607, 1·705, 1·810, 1·933, 2·080, and 2·243, the respective fractions of pitch or fractions of a whole convolution in screws of four blades will be 0·455, 0·428, 0·402, 0·378, 0·355, 0·334, 0·313, 0·294, and 0·275.

Q. And what are the corresponding proportions proper for screws of six blades?

A. Beginning with the relative resistance of 5·5 as before, the proper ratio of pitch to diameter for that and each of the successive resistances, in the case of screws with six blades, will be 1·677, 1·771, 1·891, 1·2009, 2·131, 2·262, 2·416, 2·600, 2·804; and the respective fractions of pitch will be 0·794, 0·749, 0·703, 0·661, 0·621, 0·585, 0·548, 0·515, and 0·481. These are the proportions which will give a maximum performance in every case.[1]

SCREW AND PADDLES COMBINED.

Q. Would not a screw combined with paddles act in a similarly advantageous way to a screw or paddles when aided by the wind?

A. If in any given paddle-vessel a supplementary screw be added to increase her power and speed, the screw will act in a more beneficial manner than if it had the whole vessel to propel itself, and for a like reason the paddles will act in a more beneficial manner. There will be less slip both upon the paddles and upon the screw than if either had been employed alone; but the same object would be attained by giving the vessel larger paddles or a larger screw.

Q. Have any vessels been constructed with combined screw and paddles?

A. Not any that I know of, except the 'Great Eastern.' The 'Bee' many years since was fitted with both screw and paddles, but this was for the purpose of ascertaining the relative efficiency of the two modes of propulsion, and not for the purpose of using both together.

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[1] In my *Treatise on the Screw Propeller* I have gone into these various questions more fully than would consort with the limits of this publication.—J. B.

Q. What would be the best means of accelerating the speed of a paddle-vessel by the introduction of a supplementary screw?

A. If the vessel requires new boilers, the best course of procedure would be to work a single engine giving motion to the screw with high-pressure steam, and to let the steam from the high pressure engine work the paddle-engines. In this way the power might be doubled without any increased expenditure of fuel per hour, and there would be a diminished expenditure per voyage in the proportion of the increased speed.

Q. What would the increased speed be by doubling the power?

A. The increase would be in the proportion of the cube root of 1 to the cube root of 2, or it would be 1·25 times greater. If, therefore, the existing speed were 10 miles, it would be increased to 12½ miles by doubling the power, and the vessel would ply with about a fourth less coals by increasing the power in the manner suggested.

Q. Is not high-pressure steam dangerous in steam vessels?

A. At one time it was so regarded. But it has now been generally introduced, and no evil consequences have resulted. In the case of locomotive engines, moreover, where high steam is used so widely, very few accidents have occurred. In steam vessels the only additional source of danger is the salting of the boiler. This may be prevented by the use of fresh water in the boiler, as is now the usual arrangement. The great problem of steam navigation is the economy of fuel, since the quantity of fuel consumed by a vessel will very much determine whether she is profitable or otherwise. Notwithstanding the momentous nature of this condition, however, the consumption of fuel in steam vessels was long a point to which very little attention was paid, and no efficient means were adopted in steam vessels to insure that measure of economy which was known to be attainable, and which had been attained already in other departments of engineering in which the benefits of such economy are of less weighty import. Of late years, however, this fault has been completely corrected, and marine engines are now habitually worked with less fuel than any other engines generating the same power.

Q. What effect is produced upon a steamer by being set to ply in shallow water?

A. The speed of the vessel is diminished, but at the same time the speed of the engines is increased. The water can neither get away from the bow so easily to allow the vessel to pass, nor can it so easily fill up the vacuity at the stern caused by the advance of the vessel. There is consequently a greater difference than usual between the level of the water at the bow and that at the stern, and a current sets in along the sides of the vessel, which turns the paddle-wheels or screw round with more than the usual rapidity, without, however, propelling the ship with the efficiency obtained in deep water. Practically, the effect of setting a vessel to ply in shallow water is the same as that of giving the vessel a very full bow and stern ; and it is found by experience that such vessels will go fastest when trimmed very much by the head, the effect of which is virtually to make the stern finer.

CANAL BOATS.

Q. Will a similar effect be produced if the breadth be diminished of the tract of water in which the vessel moves ?

A. The resistance which a vessel suffers in a canal will be greater than that experienced in a wide tract of water, and will vary with the sectional area of the canal relatively with that of the vessel. In the case of light boats on canals, however, it was long ago found that they were more easily drawn by horses at the gallop than at the trot, which is explained by the circumstance that when the boat travels as fast as the wave which she produces in the water of the canal, there is only one wave raised, whereas if she travels slower, so that the wave runs faster than the boat, there will be a succession of waves raised, and therefore more power consumed. It is only in narrow and shallow canals, however, that the boat can overtake the wave at speeds maintainable by horses. In deep and wide canals the wave necessarily runs ahead, and its altitude is not so great as in smaller canals.

Q. Can you give any example of the variations of resistance and of speed which a vessel of given cross-section suffers in canals of different widths ?

A. Experiments have been made in France to illustrate these points with the twin-screw-steamer 'Étoile.' This vessel is 81 feet long upon deck and 15½ feet broad. Her draught of water is 3·28 feet, and her immersed midship section is 34½ square feet. She is propelled by a single condensing engine, with cylinder 14¾ inches diameter and 16½ inches stroke. The pressure of steam is 30 lbs. per square inch, cut off at ¾ of the stroke. There is a screw in each quarter, 5¼ feet diameter and 11 feet pitch, making sixty to eighty revolutions per minute. The resistance experienced by the 'Étoile' in open water and in canals of different sections is shown in the following table:—

Experiments on Traction in Canals with the French Twin-Screw-Steamer 'Étoile.'

Place of experiment	Section of canal in sq. ft.	Ratio of section of canal to immersed section of vessel	Slip of the screw per cent.	Power exerted by the engine in horses	Speed of the vessel per hour in statute miles	Resistance in lbs. of one sq. ft. of midship section at a speed of 1 metre or 3·2808 ft. per second
Roads of Havre .	—	—	19	17	7·8	1·61
Canal of Arles .	396·115	11·5	30	17·7	6·2	2·66
Canal of Beaucaire .	286·322	8·3	30	15·8	6·0	2·82
Lateral canal of the Loire . . .	213·127	6·2	40	14·9	4·5	5·24
Canal of Briare .	118·4 to 139·9	3·4 to 4	,,	,,	3·5	,,

It may here be noted that 3·2808 feet per second is about 2·24 miles per hour.

Q. Were not experiments made in France by General Morin to ascertain the resistance and performance of light boats on canals?

A. Yes; those experiments were made with light and swift boats upon the canals at Ourcq and St. Denis, and they showed that the resistance is also affected by the amount of rubbing surface of the bottom, and that this quantity is independent of the speed. In the best examples of these boats the resistance per square foot of immersed section at a speed of 3·2808 feet per second was 2·16 lbs. The resistance per square foot of moistened surface of the bottom was 0·043 lbs. per square foot. Putting R to represent the whole resistance of the boat, S the extent of moistened surface of the bottom in square feet, K the resistance per square foot of immersed section in lbs., B^2 the area of the immersed midship section in square feet, and V the velocity in mètres per second, then $R = \cdot 043S \times KB^2V^2$. In large vessels in the open sea the value of K, which was 2·16 in the best canal boats, and 1·61 in the case of the 'Étoile' when plying in open water, is found to be considerably reduced. In the 'Pelican' it was ascertained to be 1·22 lbs., and in larger vessels 0·92 lbs. per square foot at the same speed per second.

Q. What is the best species of propeller to be used on canals?

A. On many grounds the screw is preferable to paddles, and where the depth is small twin screws may be used. But a more beneficial propeller would be one which engages the bottom of the canal, and which consequently works without slip. For many years past a species of tug-boat has been in use upon the Rhone which fulfils this indication. A great iron wheel, 20 feet diameter, armed with prongs, is set at the end of an arm, one end of which is connected with the machinery, while the other end, which carries the great iron wheel, is capable of rising and falling so as to enable the wheel to run along the bottom of the river, an opening being made through the vessel to permit this. The power of the engine is transmitted to this wheel by pitch chains, by which it is slowly rotated, and as it creeps forward it propels the vessel, dragging a train of heavily laden barges against a rapid stream. On the Rhone this is the only species of steam-vessel which has survived the introduction of competing railways.

Q. What becomes of the power expended upon the screw?

A. The vessel is put into motion by the screw at a certain velocity, and a part of the power is no doubt expended in the generation of heat, and is consequently lost. But a large part of the engine power is expended in rubbing the water into motion in the direction of the ship, and this power is in part recovered by the action of the screw, which, by giving an opposite motion to the moving water, brings it to a state of rest. Paddle-wheels do not recover any of this power, and hence, in the case of long vessels, where the water is effectually rubbed into motion, the screw is a more beneficial propeller than paddles. To enable the screw, however, to act in its most advantageous manner, it should not be introduced so close to the stern as to suck away and propel sternward the water flowing in to fill the vacuity left by the advance of the vessel, as to draw away this water will be to retard the progress of the vessel. The screw, therefore, should not work in this water, but in the water lying further aft. It has been observed, in the case of screws situated in the usual position in the dead-wood, that a corrosive action sets in upon the forward face of the screw, if formed of cast iron, which is imputed to the presence of air at this point, caused by the projection backward of the water by the screw, while the advance of the vessel causes such a competition for the water that a partial vacuum is produced at the corroded part, into which the air diffused in the water will be collected. Mr. Froude found by his experiments with models that the best effect was obtained when the propeller was placed one-third of the breadth of the model clear of the stern. By adopting this arrangement the speed was increased from 0·98 knots to 1·4 knots, and the apparent slip was reduced from 11 to 4 per cent.

Q. In the case of a fish swimming beneath the water, is the surface of the water necessarily disturbed when the fish moves?

A. No.

Q. How, then, can the fish change its position, seeing that water is incompressible?

A. By virtue of the mobility of the water. The particles which are in excess at the head are made room for by the particles which are in defect at the tail, and there is consequently a current from the head to the tail to maintain the equilibrium. In a perfect fluid, without friction or viscosity, no expenditure of power would be required to propel any object moving in it.

Q. Does the same action which exists in the case of a fish take place also in the case of a ship?

A. It does to a considerable extent. But in the case of a ship the surface of the water is also disturbed, the line of least resistance being to the surface. There is consequently an upward and downward movement of the water which has to be considered.

Q. Will not speed also be promoted by placing the midship frame at one-third of the length from the bow, instead of in the middle of the length as at present?

A. It will. The water displaced by the hull necessarily moves to the surface, and one main indication to be fulfilled is to leave this vibrating mass of water without any motion in it, as such motion implies waste of power. If the wave raised by the progress of the vessel attains its greatest elevation at the middle of the length of hull, it will attain its greatest depression at the stern post, and will have expended its energy in aggravating that depression; whereas, if the configuration of the hull be such as to place the greatest elevation of the wave at one-third of the length from the bow, the maximum depression will be at one-third of the length from the stern, and from this point the wave will again rise to its point of maximum elevation at the very stern. In this progress it will, by a proper configuration of the stern, be imparting force all along; and the motion created in the water by the vessel's progress, and which would else be lost, will be utilised for propulsion.

Q. In the case of a swift steamer, will the displacement be mostly to the surface?

A. Yes; there will be a gradual acclivity created from the stem up to midships, and thence a gradual declivity to the stern. But in reality the rise in the surface of the water will begin in advance of the stem, and it is advantageous to get the crest of the wave as far aft as possible, both so that the vessel may be always going down hill, and that a hydrostatic head instead of a depression may be created at the stern. This result has been to some extent obtained in the case of light and swift torpedo-boats.

TORPEDO-BOATS.

Q. What has been the general nature of the experience obtained with torpedo-boats?

A. In a first-class torpedo-boat 100 feet long, and with 40 tons displacement, a ton of coal will carry the vessel through a distance of 100 miles at a speed of ten miles an hour. When at her highest speed, ten tons added to the weight will take 2¼ knots off the speed. Many of these boats attain a speed of twenty knots an hour, and more than that.

Q. May not similar speeds be obtained in large vessels?

A. Applying the law of corresponding speeds already referred to as having been first indicated by M. Reech, the performance of a torpedo-boat may be made to indicate the nature of the performance to be expected from large vessels. When a torpedo-boat was driven at a speed of 10 knots, her behaviour was in all respects the same as that of a large vessel driven at a speed of 14 to 15 knots per hour. The resistance varied as the square of the speed, and the vessel changed trim a little and sank a little further into the water. As the speed increased the resistance rose more rapidly than the square, and reached as much as the 3·5th power. But as the speed was further increased, this high rate of resistance did not continue to increase, but, on the contrary, diminished, so that the same boat which, at a speed of 10 knots, experienced a resistance varying as the square, and at 13 knots as the 3·5th power, had at 18 knots a resistance varying as the 1·5th power, and beyond that a resistance varying as the simple velocity. Mr. Froude's experiments upon the friction of bodies moving in water show that up to a speed of 10 knots there is no considerable deviation from the law of the resistance increasing as the square, or, more nearly, as the 1·8th power of the velocity. But the friction at very high speeds has not been ascertained. The diminished resistance of torpedo-boats at high speeds must be imputed partly to their immersion being made less by the rising of the hull in the water at high speeds. There is no doubt, moreover, that in all vessels a wave of a volume at least equal to the hull travels with the vessel, as is more conspicuously manifested in the case of canal boats; and in ordinary vessels, as in canal boats, the result will be best when the vessel travels at the same speed as this wave, and when the crown of the wave is brought considerably abaft the midship frame, so as to deliver its momentum before parting with the vessel, whereby the work of propulsion will be assisted.

Q. What species of screw is found best in fast torpedo-boats?

A. A two-bladed screw is better than a three-bladed, and it should be somewhat astern of the rudder-post, and be wholly immersed, as when it protrudes above the water it draws in air, and lessens the speed of the boat in the proportion of ·7 to ·5. A change of trim will sometimes correct this defect. Twin screws have not been found so convenient or satisfactory as single screws. But probably Ericsson's original arrangement of two screws on the same axis, revolving in opposite directions, would give a better result than a single screw. With large screws there has been found to be a negative slip of 1 to 1½ per cent., and a worse performance. In fast boats the slip should not be less than 12, or more than 27 per cent. It is found that the slip increases with the speed up to 18 knots, and then diminishes.

Q. What is the thickness of the plates of which these swift vessels are built?

A. The plates are of thin Bessemer steel, galvanised, and in some cases have been as thin as $\frac{1}{40}$th of an inch.

Q. Is there not a good deal of vibration in such thin vessels at high speeds?

A. There is a good deal of vibration with certain speeds, but at both lower and higher speeds the vibration stops—to be renewed at other speeds. Thus, it has been found that in a boat 86 feet long there was very great vibration when the engines were making 200, 400, 600, or 800 revolutions per minute. But at the intermediate speeds of 300, 500, and 700 revolutions the vibrations ceased altogether.

Q. Is the vibration due to the engines or due to the boat?

A. It is due to the combination. A slight vessel, like a suspension bridge, has a vibration of its own, which may become very great if the force be applied and withdrawn synchronously with this natural vibration. A suspension bridge has been broken down by a troop of soldiers marching over it and keeping step to the tune of a fife; and in torpedo-boats, when the period of maximum vibration is found to be coincident with that velocity of engine power which gives full speed, the pitch of the screw is altered so as to extinguish the vibration by altering the engine speed. This was done in the case of the 'Lightning,' which, at an engine speed of 360 revolutions per minute, vibrated very much. The stern vibration is found to be twice as rapid as the bow vibration.

Q. In torpedo-boats, are there any limits of size?

A. There are two classes of torpedo-boats. The first-class boats have sufficient size and power to be able to keep at sea themselves. The second-class boats are intended to be carried by large vessels in the same way as ordinary row-boats are, and when not required to be used they are hauled up and hung by davits. A second-class boat will be able to exert 150 horses-power, with 650 revolutions, and will attain a speed of 17½ knots. Her weight with steam up will be about 12½ tons. A first-class torpedo-boat will exert a power of about 470 horses, with 445 revolutions, and will attain a speed of 21¾ knots. Such a boat will be about 110 feet long, 12 feet broad, and will draw 6 feet 3 inches of water, and the displacement will be about 52½ tons. In the first and second-class boats alike the engines are of the compound type.

Q. In what way did the torpedo class of boats originate?

A. In 1860, boats 60 feet long and 6 feet wide were drawn by horses on the Regent's Canal, in London, at a speed of 10 miles an hour. Mr. Thorneycroft built a small steamer—the 'Nautilus'—with the design of equalling this performance, and she attained a speed of between 11 and 12 miles per hour. The 'Lightning' was afterwards built, which, with a propeller 3 feet in diameter and 400 horses-power, attained a speed of 18 knots.

Q. Cannot similar means be employed to accelerate the speed in large vessels?

A. A vessel like the 'Iris,' of 3,700 tons, would, at a speed of 20 knots, comport itself in much the same way as a 20-knot torpedo-boat does at a speed of 10 knots. To act in the same way as the torpedo-boat at its maximum speed, the large vessel, it has been computed, would require to be brought up to a speed of 35 to 40 knots. But it has also been reckoned that two propellers, each 7 feet in diameter, would be sufficient to do this.

Q. How does the coefficient of torpedo-boats compare with that of modern sea-going vessels?

A. The 'Germanic,' with a displacement of 8,525 tons and 5,434 horses-power, steamed across the Atlantic at a speed of 15·8 knots, giving by the formula $\frac{V^3 D^{\frac{2}{3}}}{H\text{-}P}$ a coefficient of 303. That of the 'Iris' is 189, and that of a first-class torpedo-boat 224. The 'Miranda,' with a displacement of 3·7 tons, required 64 horses-power for 16·2 knots.

Q. Does a torpedo-boat alter her trim on being put into motion?

A. Yes; she rises at the bow. A boat 100 feet long will rise about 3½ feet at a speed of 20 knots, and allowance has to be made in fixing the position of the boiler for this change of trim.

HYDRAULIC PROPULSION.

Q. Are boats sometimes propelled by the reaction of a stream of water issuing astern?

A. Yes; but hydraulic propulsion up till now has not been very successful. Its most beneficial application would probably be to the propulsion of lifeboats, as the propelling jets act whether in th water or out of it; and this is a valuable property in the case o small boats navigating an agitated sea.

Q. What was the nature of the performance obtained with th water-propelled steamer 'Waterwitch'?

A. The 'Waterwitch' is an armoured gunboat of 1,161 to displacement, and with 786 indicated horses-power she attained speed of 9·3 knots. The 'Viper,' a screw boat with a displaceme of 1,180 tons, attained a speed of 9·58 knots with 696 horses-pow The machinery of the 'Waterwitch' was designed by Ruthv The vessel is propelled by a centrifugal pump 14 feet diame forcing water out of two water jets, each 24 inches diameter, at surface of the water. There are 5·2 tons of water discharged second at a speed of 29 feet per second, or about 17½ knots per h

Q. What other comparisons have been made between the systems of propulsion?

A. In 1878 a Swedish hydraulic torpedo-boat was tried a boat driven by twin screws. The boats were each long, 10 feet 9 inches broad, and of 20 to 21 tons displacement. The screws, with 90 horses-power, drove the boat 10 knots. The centrifugal pump, with 78 horses-power, drove the boat 8·12 knots. The displacement coefficient with the screws was 82, and with the water-jets 52·5. In 1880, Thorneycroft fitted a torpedo-boat to work with hydraulic propulsion. The length of the boat was 66 feet 4 inches, beam 7½ feet, draught 2½ feet, and displacement 14·4 tons. The turbine pump was 2½ feet diameter, and made 428 revolutions per minute. There was a discharge nozzle above the water on each side, 9 inches diameter. The pump discharged one ton of water per second at a velocity of 37½ feet per second. With a power of 167 horses, the speed obtained was 12·6 knots. Similar screw-boats with 170 horses-power attained a speed of 17·3 knots. Jet propulsion, therefore, so far as regards the dynamical result, is inferior in efficacy to screw propulsion; but it may be used with advantage in shallow water, where there is not depth enough for the screw, and where the issuing water may help to fill up the vacuity at the stern caused by the progress of the boat through the water. In most cases, moreover, in which water-jet propellers have hitherto been tried, the area of the jet orifices has been too small, and consequently too great a velocity has been imparted to the issuing water. The difference between the velocity of the vessel and the velocity of the issuing jet represents the slip, and just in the proportion of the disparity of these velocities will be the waste of power from slip. The theoretical condition which should be sought to be approximated to, is that the rope of water should be practically undisturbed, and that by means of it the vessel should haul herself along, the whole motion being in the vessel and none at all in the water. The velocity of the issuing water, it is clear, will be small in the proportion in which the area of the discharging orifice is great; and a large mass of water to act upon and a small velocity of efflux are necessary conditions.

PNEUMATIC PROPULSION.

Q. May not some other fluid than water be employed for jet propulsion?

A. Yes; a more convenient and more economical expedient would, I believe, be propulsion by air, or rather by the smokeless products of combustion.

Q. How could this idea be carried into effect?

A. Liquid fuel is found to have a greater heating efficiency than coal. If certain quantities of liquid fuel and air were to be forced into a furnace, a smokeless combustion at a high pressure could be maintained therein, and jets issuing from this furnace and pointing sternward beneath the water would propel the vessel in much the same way that water does.

Q. But would not such jets be necessarily smaller than water jets, and therefore involve more slip?

A. Not necessarily. The air jets could, by being presented obliquely to the water, be made to act upon a very large volume of water, so that the water would not be much moved, and the slip would be small in the proportion of the smallness of the motion imparted to the water.

Q. Then no boiler would be required under such an arrangement?

A. No; but a jet of water could be introduced among the products of combustion as they emerge from the furnace, so as to moderate the temperature and increase the volume. The resulting steam would escape with the products of combustion, and be condensed by the water outside.

CHAPTER VIII.

EXAMPLES OF MODERN ENGINES AND BOILERS.

LAND ENGINES AND BOILERS.

Q. You have already stated that in good land and marine boilers about 9 square feet of heating surface are required to evaporate a cubic foot of water in the hour without serious loss of heat up the chimney. What is the proportion of surface necessary in locomotive boilers to attain the same result?

A. About 6 square feet.

Q. What is the cause of the difference?

A. In locomotives the fire-box is usually of copper and the tubes of brass. These metals are better conductors of heat than the iron of which the parts of land and marine boilers are generally formed. The main cause of the difference, however, lies in the higher temperature of locomotive furnaces, owing to the greater intensity of the draught.

Q. Are all parts of the heating surface equally effective for evaporation?

A. No; there is a very great difference, depending upon the temperatures to which the parts have been respectively subjected. Thus, in the experiments made by Mr. Graham, of which the results are recorded in the 'Transactions of the Literary and Philosophical Society of Manchester,' for 1858, four open tin pans, each a foot square, were set in a row in brickwork. A grate, a foot square, was placed under the first pan, and a flue from it passed beneath the other pans successively and conducted the smoke to the chimney. Taking the evaporative efficacy of the first pan as 100, that of the second pan was 27, of the third 13, and of the fourth 8. In another series of experiments, three cylinders of plate iron, each 3 feet diameter, 3 feet long, and ¼ inch thick, were set horizontally, end to end, in brickwork, with a grate 2 feet broad and 3 feet long under the first cylinder; and a flue, concentric with the cylinders, 4 inches in radial depth and extending up to the semi-diameter, conducted the smoke beneath the other cylinders to the chimney. Taking the evaporative efficacy per square foot of heating surface in the first cylinder at 73, that of an equal area in the second cylinder was 18½, and that in the third cylinder 8½, showing that about three-fourths of the total evaporation per square foot was done in the first cylinder, and only one-twelfth in the third.

Q. Have similar results been obtained in the case of locomotive boilers?

A. Yes; so far back as 1842 Mr. Edward Woods demonstrated this by conclusive experiment. Successive portions of the flue-tubes of a locomotive, 5½ feet long in all, were separated from the adjoining portions by vertical diaphragms. The first compartment was 6 inches long, and each of the others 12 inches. It was found that the evaporative duty per square foot of the first compartment was nearly the same as that of the fire-box, that of the second compartment about one-third as much, and that of the remaining compartments very small. The first 6 inches of tube, in fact, did more work than the remaining 60 inches.

Q. Have these results been confirmed by other experimentalists?

A. Yes, by several; but I will only recapitulate those obtained by M. Pétiet, of the Northern Railway of France. He divided a locomotive boiler with tubes 12 feet 3 inches long into five compartments. The first compartment consisted of the fire-box with 3 inches of length of the tubes. The four tube-sections were each 3·02 feet long, and each presented 179 square feet of surface, while the surface of the fire-box and 3 inches of tube was 76·43 square feet. The water evaporated per square foot per hour with coke was, in the first or fire-box section, 24·5 lbs.; in the second or first tube section, 8·72 lbs.; in the third, 4·42 lbs.; in the fourth, 2·52 lbs.; and in the fifth, 1·68 lbs. M. Havrez, from these and other experiments, deduces the law that the quantities of water evaporated by equal consecutive lengths of flue tubes decrease in geometrical progression, while the distances from the commencement of the series increase in arithmetical progression. The results of Mr. D. K. Clark's experiments on locomotive boilers are set forth in his valuable work on 'Railway Machinery,' and also in a paper on 'The Evaporative Performance of Steam Boilers,' read before the Institution of Civil Engineers in 1876.

Q. Will you give an example of a modern land boiler of ordinary construction?

A. For this purpose I will take an ordinary Galloway boiler with cylindrical shell and internal furnaces. Such a boiler is shown in fig. 105, where A is the boiler shell, shown in section; B the furnace; C the flue, in which are set several conical pipes open to the water in the boiler; D is the ashpit; E the furnace door; F the brickwork in which the boiler is set, and in which a flue L L is formed, through which the smoke passes beneath the boiler to the chimney M; G is a steam dome or steam reservoir placed on top of the boiler; N is the stop valve, through which the steam is admitted to the engine; P is the safety valve; Q the man-hole door, which is removed when a man is required to enter the boiler for cleaning or repairs; R is the steam gauge; and S the glass tube for showing the water-level within the boiler. The smoke, on reaching the end of the furnace flue, divides and returns to the front of the boiler through flues formed in the brickwork F, and thence descends into the flue L L, which conducts it to the chimney.

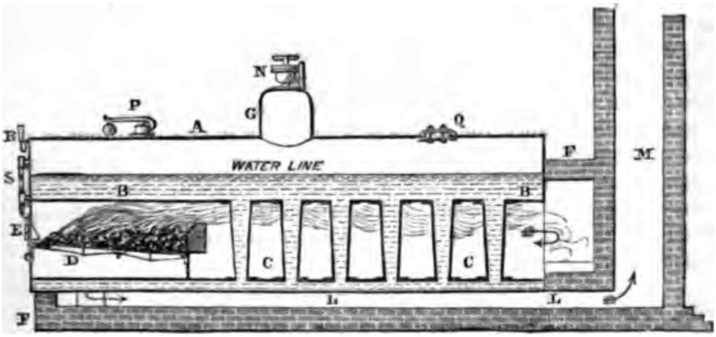


Fig. 105.—Section of Galloway's Boiler.

Q. What are the advantages and defects of this species of boiler?

A. Its main merit is that it is strong, by reason of being cylindrical. But this distinction it only possesses in common with all other cylindrical boilers, and there are few others now made.

Q. Are the internal furnaces beneficial?

A. I think not. The furnace flue is necessarily of very small diameter in boilers of this kind, especially if they are of moderate power—and this circumstance limits the thickness of fire which can be adopted, and also the amount of declivity which can be given to the furnace bars.

Q. Is a thin fire disadvantageous?

A. If a fire be spread over a large surface its temperature is diminished, and this impairs the completeness of the combustion and also the rapidity of the transmission of heat to the water. The best thickness of the fire in any given boiler will depend very much upon the intensity of the draught and the size of the pieces of coal used. In furnaces operating with a natural draught and fed with coal of good quality, the pieces of which vary in size from that of a hazel nut to that of an egg, it is found by experiment that a thickness of fire of about 14 inches gives the best result. In boilers of the Galloway type no such thickness can be got unless the boiler be made of very large size, and if so made the condition introduces other evils.

Q. What is the nature of the impediment to the use of a thick fire in these boilers?

A. The furnace flue, whatever its diameter, has to be divided horizontally into two parts by the grate, the upper portion constituting the furnace and the lower portion the ashpit. If the flue be 3 feet in diameter, as it is usually made in cylindrical marine boilers, the furnace can be made 18 inches deep from the crown to the bars, and the ashpit about 14 inches deep, after allowing for the depth of the grate. If the fire be made 14 inches thick, there will only be 4 inches of space between the surface of the fire and the crown of the furnace, which is quite too shallow a space for throwing the coal through in stoking the fire. The width of the fire surface, moreover, at 4 inches from the crown is greatly contracted, and affords an inadequate area for the smoke to pass through on its way to the chimney, especially as the furnace bridge should always extend to a greater height than the surface of the fire. It is clear, therefore, that in a 3-feet furnace flue nothing like 14 inches thickness of fire can be got, and even this size of flue involves a very large diameter of boiler. With two 3-feet furnace flues and 4 inches of water space, the diameter of shell where the furnaces are inserted must be at least 7 feet, without counting thicknesses of plate; and as the furnaces are not inserted in the middle of the boiler but considerably below that, the diameter of the boiler which admits them must necessarily be so large as to make it impossible to obtain the strength necessary for high pressures without an objectionable amount of weight. Thus, in the boilers of the 'Head-Quarters' with 60 lb. steam, where the two furnace flues are each 3 feet 3 inches diameter, the shell comes out to be 10 feet 10 inches diameter and cannot be made less.

Q. Of what thickness would the iron of such a boiler require to be, as compared with one of 5 feet 5 inches diameter of shell and carrying the same pressure?

A. It would require to be of twice the thickness.

Q. Is 60 lbs. per square inch a common pressure in modern boilers?

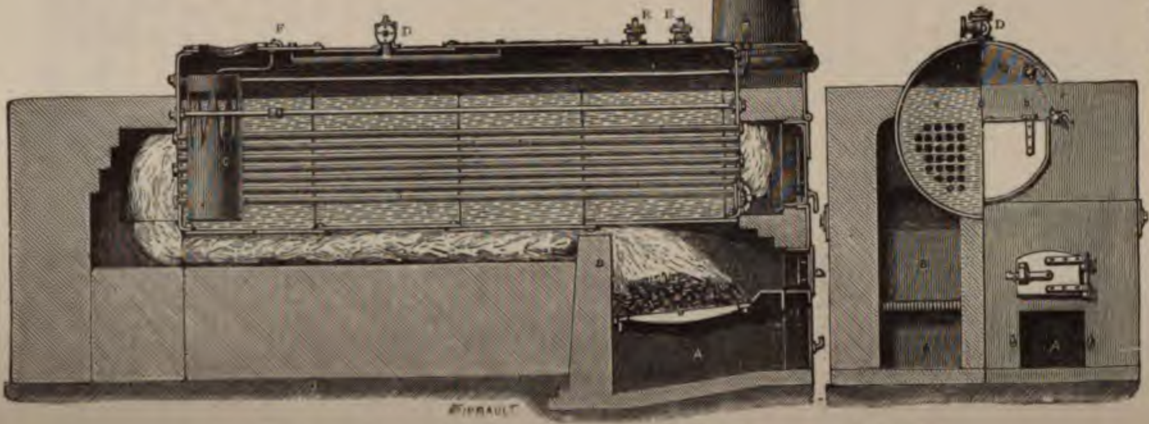
A. It is now reckoned rather a low pressure even for condensing engines, while for high-pressure engines it is quite too low to be economical. About double this pressure, or 120 lbs. per square inch, is the lowest pressure which should now be entertained in high-pressure engines.

Q. Supposing the boilers of the 'Head-Quarters' to be proportioned to carry 120 lb. steam, would the thickness of the iron of which they are composed have to be doubled?

A. Yes; so far as regards strain, increasing the pressure is tantamount to increasing the diameter. A 10 foot 10 inch boiler with 120 lb. steam requires to have as thick plates as a 21 foot 8 inch boiler with 60 lb. steam. For high pressures the plan of fitting cylindrical boilers with internal furnaces is clearly inadvisable.

Q. Will you specify some other species of boiler which is not attended with the same inconveniences?

A. A barrel of tubes laid on its side with a fire beneath appears to be a preferable arrangement for land purposes. Such a boiler is shown in figs. 106 and 107, where A is the ash-pit; B, the furnace bridge; C, a collecting vessel into which the mud and deposit, which would else collect upon the bottom of the boiler or would go to form scale upon the tubes, are collected; D is a cock conducting the steam from a perforated internal steam-pipe to the engine; E E are safety valves; and F is a pipe through which the sediment is from time to time blown out of the collecting vessel C. It will be obvious from this delineation that the boiler consists of a cylinder of tubes, resting upon its side for its entire length on a brick wall, upon each side of which a furnace is formed of brickwork. The smoke and flame travel beneath the bottom and along the sides of the boiler to the end, and return through the tubes to the front, where the chimney is situated. Before entering the tubes the smoke is deflected downward by a hanging bridge, which



Figs. 106 and 107.—Vertical and Cross-sections of a 90-horse Tubular High-pressure Land Boiler
Scale, ⅛th inch = 1 foot.

the hot air in contact with the sides, and it is found that by rangement no soot collects on the outside of the boiler. It found that the brickwork becoming very hot helps to burn oke, and by the radiation of its heat increases the efficacy heating surface. Under this arrangement there are two short es which are easily fired, and any thickness of fire can be yed which is found advisable. There is sufficient space d round the tubes to permit a free circulation of the water, y the efficacy of the heating surface is increased. The is strong, light, and inexpensive, and enables high pressures mployed with safety.

What is the object of employing a perforated internal steam-

By taking the steam off over a considerable length of the instead of from one spot, it reduces very materially the lia- o priming. This will be further reduced by working with ck, D, partly shut.

Will you explain the structure and mode of action of the ing vessel?

The collecting vessel is a cylinder of sheet iron, closed at ttom but open at the top, and with a number of V-shaped ations in its sides extending above and below the water-level. particle of grit or mud within the boiler is ballooned to the e by a bubble of steam so soon as ebullition commences, and ot settle on the bottom so long as the agitation of the water ues. If a quiescent spot be provided in the boiler the moving le will settle there, and the collecting cylinder provides such , as the water within it, not being exposed to the heat of the perfectly tranquil. The water which enters through the V ations consequently soon deposits any particles suspended nd as this is constantly being replaced by other water, the of the water in the boiler is soon cleared of its foreign par- The lime separated from calcareous water, and which in ry boilers forms scale, will be collected as mud in a collecting , and may thus be expelled by occasional blowing off—say, in ory boiler for a few minutes at each meal hour.

What kind of engine is used with this species of boiler?

Any ordinary form of engine may be used with it. But if oiler be made on the proportions here shown, the engine be a high-pressure one with a blast-pipe in the chimney, as oiler tubes are proportioned on that supposition. It is best also that the engine should be of the high-speed type, as in those engines the demand for steam being more nearly continuous, a moderate amount of steam-room suffices. Such an engine is shown in fig. 108. The crank consists of two cast-iron discs, one side of which is heavier than the other, so as to balance the momentum of the piston and its connections. The slide-valve is of the piston kind, so as to be in equilibrium at all pressures, as ordinary three-ported valves with high pressures were found to wear. The eccentric which works the valve also works the feed-pump. There is a small three-ported starting-valve worked by a handle, shown in the figure, and this valve also serves as an escape-valve for both ends of the cylinder should priming occur. The steam is cut off by the slide-valve at half-stroke, and any additional amount of expansion that is needed is got by throttling. Such engines are light, strong, and inexpensive. They are very equable in their action, work without tremor, and are economical in fuel.

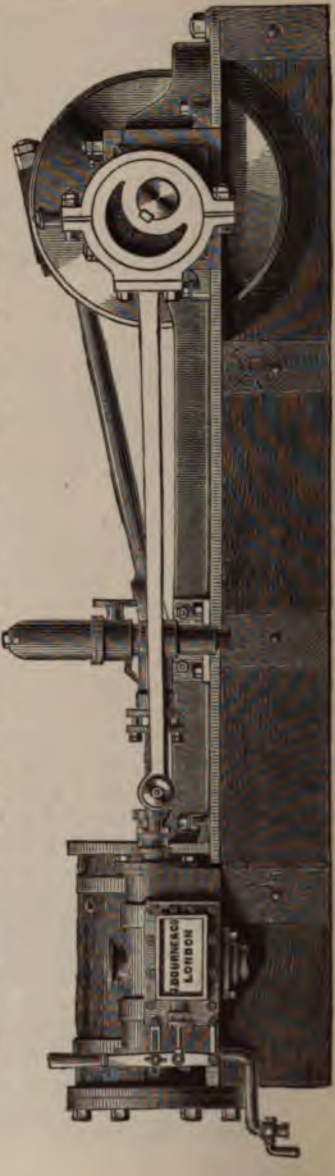


Fig. 108.—Elevation of a High-pressure High-speed Horizontal Engine.

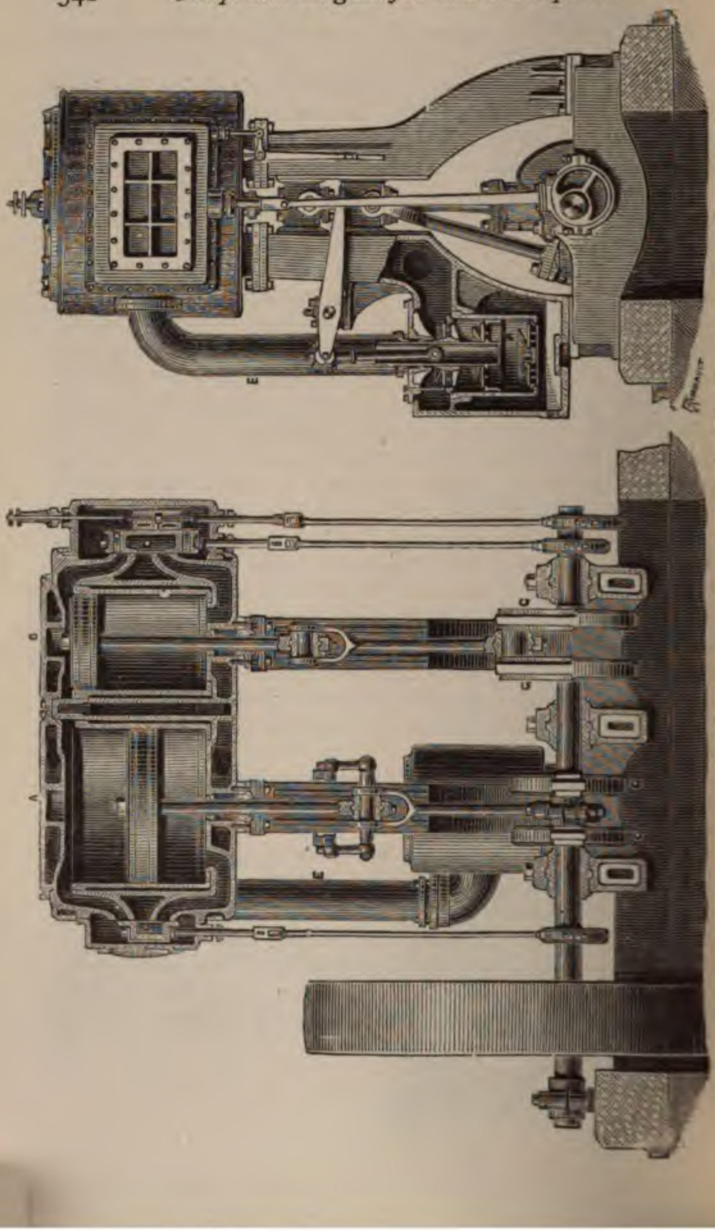
Scale, $\frac{1}{8}$th of an inch to a foot.

Q. Are compound engines of the marine type sometimes used for land purposes?

A. They are sometimes so used, and their action has been found to be highly satisfactory. They are economical in fuel, are much more equable in their action than the slow-moving beam-engines heretofore used, are inexpensive to erect from the absence of foundations, and are not costly to buy relatively with the power they generate. An engine of this character is shown in figs. 109 and 110, where A is the low-pressure and B the high-pressure cylinder; C, the high-pressure slide, at the back of which there are two adjustable plates moved by a separate eccentric, for determining the amount of expansion in the high-pressure cylinder; D is the slide-valve of the low-pressure cylinder; E is the eduction pipe leading from the low-pressure valve to the condenser; F is the foot-valve which admits the water in the condenser to the air-pump; G G are the cranks, which have balance weights attached to them by iron straps to balance the weight and momentum of the pistons and their connections. Both cylinders, both on the sides and at the ends, are steam-jacketed. The cylinder proper is in each case formed of a bush of hard cast-iron set in a somewhat larger cylinder, the space between being filled with steam, which constitutes the jacket. To make the jacket tight at the ends, each bush is formed at the lower end with a flange turning inwards, which is bolted firmly to the bottom of the containing cylinder, while the upper part of each bush is enlarged to form a slipping joint, which is made steam-tight by means of asbestos or other packing. The power of the engine is communicated to the machinery it drives by means of a fly-wheel pulley.

Q. Would a boiler of the kind you have described as suitable for high-pressure land engines be suitable for this engine, seeing that it is a land engine also?

A. No; it would not be suitable if the same proportions were observed. But it would be suitable if shortened, increased in diameter, and fitted with a larger number of tubes of a larger bore. It is clear that with a sluggish draught long tubes are a mistake, as the heat will be absorbed in the first part of the tube, leaving the other part nothing to do; whereas with a strong draught, if the tubes be very short, a good deal of the heat will go up the chimney.



Figs. 109 and 110.—Vertical Section and End View of a Compound Land Engine of the Marine type. 100 actual H.P.

MODERN MARINE ENGINES.

Q. You have stated that the best form of engine for paddle-steamers is the oscillating engine. Are oscillating compounds sometimes made?

A. They are, but not often. The external appearance of such engines is much the same as that of ordinary engines, the cylinders being of the same apparent size. But a high-pressure cylinder is placed within one of the cylinders, and the space between this high-pressure and its containing cylinder constitutes a reservoir for the steam which the high-pressure cylinder delivers.

Q. Will you describe the structure of an ordinary oscillating marine engine as made by Messrs. Penn?

A. To do this it will be expedient to take an engine of a given power, and then the sizes may be given as well as an account of the configuration of the parts. We may take for an example a pair of engines of 21½ inches diameter of cylinder, and 22 inches stroke, rated by Messrs. Penn at 12 nominal horses-power each. The cylinders of this oscillating engine are placed beneath the cranks, and, as in all Messrs. Penn's smaller engines of similar size, the piston-rod is connected to the crank-pin by means of a brass cap, provided with a socket, by means of which it is cuttered to the piston-rod. There is but one air-pump, which is situated within the condenser between the cylinders, and it is wrought by means of a crank in the intermediate shaft—this crank being cut out of a solid piece of metal as in the formation of the cranked axles of locomotive engines. The steam enters the cylinder through the outer trunnions, or the trunnions adjacent to the ship's sides, and enters the condenser through the two midship trunnions—a short three-ported valve being placed on the front of the cylinder to regulate the flow of steam to and from the cylinder in the proper manner. The weight of this valve on one side of the cylinder is sometimes balanced by a weight hung upon the other side of the cylinder; but in the most recent engines this weight is discarded, and two valves are used, which balance one another. The framing consists of an upper and lower frame of cast iron, bound together by eight malleable iron columns. Upon the lower frame the pillow blocks rest which carry the cylinder trunnions, and the condenser and the bottom frame are cast in the same piece. The upper frame supports the paddle-shaft pillow blocks; and pieces are bolted on in continuation of the upper frame to carry the paddle-wheels, which are overhung from the journal.

Q. What are the dimensions and arrangement of the framing?

A. The web, or base-plate, of the lower frame is ¾ of an inch thick, and a cooming is carried all round the cylinder, leaving an opening of sufficient size to permit the necessary oscillation. The cross-section of the upper frame is that of a hollow beam, 6 inches deep, and about 3½ inches wide, with holes at the sides to take out the core; and the thickness of the metal is $\frac{13}{16}$ths of an inch, but would be better if made a little thicker. Both the upper and the lower frame are cast in a single piece, with the exception of the continuations of the upper frame, which support the paddle-wheels. An oval ring, 3 inches wide, is formed in the upper frame, of sufficient size to permit the working of the air-pump crank; and from this ring feathers run to the ends of the cross-portions of the frame, which support the intermediate shaft journals. The columns are 1½ inch in diameter; they are provided with collars at the lower ends, which rest upon bosses in the lower frame, and with collars at the upper ends for supporting the upper frame; but the upper collars of two of the corner columns are screwed on, so as to enable the columns to be drawn up when it is required to get the cylinders out. The cross-section of the bottom frame is also of the form of a hollow beam, 7 inches deep, except in the region of the condenser, where it is, of course, of a different form. The depth of the boss for the reception of the columns is a little more than 7 inches deep on the lower frame, and a little more than 6 inches deep on the upper frame; and the holes through them are so cored out, that the columns only bear at the upper and lower edges of the hole, instead of all through it—a formation by which the fitting of the columns is facilitated.

Q. What are the dimensions of the condenser?

A. The condenser, which is cast upon the lower frame, consists of an oval vessel, 22½ inches wide, by 2 feet 4¼ inches long, and 1 foot 10½ inches deep; it stands 9 inches above the upper face of the bottom frame, the rest projecting beneath it; and it is enlarged at the sides by being carried beneath the trunnions.

Q. What are the dimensions of the air-pump?

A. The air-pump, which is set in the centre of the condenser, is 15¼ inches in diameter, and has a stroke of 11 inches. The foot-valve is situated in the bottom of the air-pump and its seat consists of a disc of brass, in which there was formerly a rectangular flap-valve, opening upwards, but rounded on one side to the circle of the pump, and so balanced as to enable the valve to open with facility. The balance weight, which was formed of brass cast in the same piece as the valve itself, operated as a stop, by coming into contact with the disc which constitutes the bottom of the pump, the disc being recessed opposite to the stop to enable the valve to open sufficiently. But indiarubber valves are now usually employed. This disc is bolted to the barrel of the pump by means of an internal flange, and before it can be removed the pump must be lifted out of its place. The air-pump barrel is of brass, to which is bolted a cast-iron mouthpiece, with a port for carrying the water to the hot-well; and within the hot-well the delivery valve, which consists of a common flap-valve, is situated. The mouthpiece and the air-pump barrel are made tight to the condenser, and to one another, by means of metallic joints carefully scraped to a true surface, so that a little white or red lead interposed makes an airtight joint. The air-pump bucket is of brass, and the valve of the bucket is of the common pot-lid or spindle kind, or else is formed of an indiarubber disc falling on a grid. The injection water enters through a single cock in front of the condenser—the jet striking against the barrel of the air-pump. The air-pump rod is maintained in its vertical position by means of guides, the lower ends of which are bolted to the mouth of the pump, and the upper to the oval in the top frame, within which the air-pump crank works; and the motion is communicated from this crank to the pump-rod by means of a short connecting rod. But the air-pump is sometimes now made with a trunk, and these guides are dispensed with. The lower frame is not set immediately below the top frame, but 2½ inches behind it, and the air-pump and condenser are 2½ inches nearer one edge of the lower frame than the other.

Q. What are the dimensions of the cylinder?

A. The thickness of the metal of the cylinder is $\frac{9}{16}$ths of an inch; the depth of the belt of the cylinder is 9½ inches, and its greatest projection from the cylinder is 2½ inches. The distance from the lower edge of the belt to the bottom of the cylinder is 11½ inches, and from the upper edge of the belt to the top flange of the cylinder is 9 inches. The trunnions are 7¼ inches diameter in the bearings, and 3½ inches in width; and the flanges to which the glands are attached for screwing in the trunnion packings are 1½ inch thick, and have ⅞ths of an inch of projection. The width of the packing space round the trunnions is $\frac{5}{8}$ths of an inch, and the diameter of the pipe passing through the trunnions $4\frac{5}{8}$ths, which leaves $\frac{11}{16}$ths for the thickness of the metal of the bearing. Above and below each trunnion a feather runs from the edge of the belt or bracket between 3 and 4 inches along the cylinder, for the sake of additional support; and in large engines the feather is continued through the interior of the belt, and cruciform feathers are added for the sake of greater stiffness. The projection of the outer face of the trunnion flange from the side of the cylinder is $6\frac{1}{2}$ inches; the thickness of the flange round the mouth of the cylinder is $\frac{3}{4}$ of an inch, and its projection $1\frac{3}{8}$ inch; the height of the cylinder stuffing-box above the cylinder cover is $4\frac{1}{8}$ inches, and its external diameter $4\frac{3}{8}$ inches—the diameter of the piston-rod being $2\frac{1}{8}$ inches. The thickness of the stuffing-box flange is $1\frac{1}{8}$ inch.

Q. Will you describe the nature of the communication between the cylinder and condenser?

A. The pipe leading to the condenser from the cylinder is made somewhat bell-mouthed where it joins the condenser, and the gland for compressing the packing is made of a larger internal diameter in every part, except at the point at which the pipe emerges from it, where it accurately fits the pipe, so as to enable the gland to squeeze the packing. By this construction the gland may be drawn back without being jammed upon the enlarged part of the pipe; and the enlargement of the pipe towards the condenser prevents the air-pump barrel from offering any impediment to the free egress of the steam. The gland is made altogether in four pieces; the ring which presses the packing is made distinct from the flange, to which the bolts are attached which force the gland against the packing; and both ring and flange are made in two pieces, to enable them to be got over the pipe. The ring is half-checked in the direction of its depth, and is introduced without any other support to keep the halves together, than what is afforded by the interior of the stuffing-box; and the flange is half-checked in the direction of its thickness, so that the bolts, which press down the ring by passing through this half-checked part, also keep the segments of the flange together. The bottom of the trunnion packing space is contracted to the diameter of the eduction pipe, so as to prevent the packing from being squeezed into the jacket; but the eduction pipe does not fit quite tight into this contracted part, but, while in close contact on the lower side, has about $\frac{1}{32}$nd of an inch of space between the top of the pipe and the cylinder, so as to permit the trunnions to wear to that extent without throwing a strain upon the pipe. The eduction pipe is attached to the condenser by a flange joint, and the bolt-holes are all made somewhat oblong in the perpendicular direction, so as to permit the pipe to be slightly lowered, should such an operation be rendered necessary by the wear of the trunnion bearings; but, in practice, the wear of the trunnion bearings is found to be so small as to be almost inappreciable.

Q. Will you describe the valve and valve-casing?

A. The length of the valve-casing is 16½ inches, and its projection from the cylinder is 3½ inches at the top, 4¼ inches at the centre, and 2½ inches at the bottom, so that the back of the valve-casing is not made flat, but is formed in a curve. The width of the valve-casing is 9 inches, but there is a portion of the depth of the belt 1½ inch wider, to permit the steam to enter from the belt into the casing. The valve-casing is attached to the cylinder by a metallic joint; the width of the flange of this joint is 1¼ inch, the thickness of the flange on the casing ½ inch, and the thickness of the flange on the cylinder ⅝ths of an inch. The projection from the cylinder of the passage for carrying the steam upwards and downwards, from the valve to the top and bottom of the cylinder, is 2¼ inches, and its width externally 8⅝ inches. The valve is of the ordinary three-ported description, and both cylinder and valve faces are of cast iron.

Q. What description of piston is used?

A. The piston was formerly packed with hemp, but the junk-ring was made of malleable iron, as cast-iron junk-rings had been found liable to break. There were four plugs screwed into the cylinder cover, which, when removed, permitted a box-key to be introduced, to screw down the piston packing. The screws in the junk-ring were each provided with a small ratchet, cut in a washer fixed upon the head, to prevent the screw from turning back; and the number of clicks given by these ratchets, in tightening up the bolts, enabled the engineer to know when they had all been tightened equally. In more recent engines, however, and especially in those of large size, Messrs. Penn employ for the piston packing a single metallic ring with tongue-piece and indented plate behind the joint. This ring is sometimes packed behind with hemp squeezed by the junk-ring as in ordinary hemp-packed pistons. But in general the hemp packing is now dispensed with, and the piston-ring is kept tight against the cylinder by springs interposed between the piston and the ring.

Q. Will you describe the construction of the cap for connecting the piston-rod with the crank-pin?

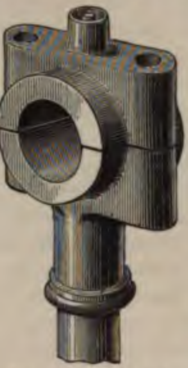


Fig. 111.—Piston-rod Cap.
Messrs. Penn.

A. The cap for attaching the piston-rod to the crank-pin, which is exhibited in perspective in fig. 111, is formed altogether of brass, which brass serves to form the bearing of the crank-pin. The external diameter of the socket by which this cap is attached to the piston-rod is $3\frac{5}{16}$ inches. The diameter of the crank-pin is 3 inches, and the length of the crank-pin bearing $3\frac{7}{8}$ inches. The thickness of the brass around the crank-pin bearing is 1 inch, and the upper portion of the brass is secured to the lower portion by means of lugs, which are of such a depth that the perpendicular section through the centre of the bearing has a square outline measuring 7 inches in the horizontal direction, $3\frac{7}{8}$ inches from the centre of the pin to the level of the top of the lugs, and $2\frac{1}{2}$ inches from the centre of the pin to the level of the bottom of the lugs. The width of the lugs is 2 inches, and the bolts passing through them are $1\frac{1}{4}$ inch in diameter. The bolts are tapped into the lower portion of the cap, and are fitted very accurately by scraping where they pass through the upper portion, so as to act as steady-pins in preventing the cover of the crank-pin bearing from being worked sideways by the alternate thrust on each side. The distance between the centres of the bolts is 5 inches, and in the centre of the cover, where the lugs, continued in the form of a web, méet one another, an oil-cup, $1\frac{5}{8}$ inch in diameter, $1\frac{1}{8}$ inch high, and provided with an internal pipe, is cast upon the cover, to contain oil for the lubrication of the crank-pin bearing. The depth of the cutter for attaching the cap to the piston-rod is $1\frac{1}{4}$ inch, and its thickness is $\frac{3}{8}$ths of an inch.

Q. Will you describe the means by which the air-pump rod is connected with the crank which works the air-pump?

A. A similar cap to that of the piston-rod attaches the air-pump crank to the connecting-rod by which the air-pump rod is moved, but in this instance the diameter of the bearing is 5 inches, and the length of the bearing is about 3 inches. The air-pump connecting-rod and cross-head are shown in perspective in fig. 112. The thickness of the brass encircling the bearing of the shaft is $\frac{3}{4}$ of an inch upon the edge, and 1⅛ inch in the centre, the back being slightly rounded; the width of the lugs is 1⅝ inch, and the depth of the lugs is 2 inches upon the upper brass, and 2 inches upon the lower brass, making a total depth of 4 inches. The diameter of the bolts passing through the lugs is 1 inch, and the bolts are tapped into the lower brass, and accurately fitted into the upper one, so as to act as steady-pins, as in the previous instance. The lower eye of the connecting-rod is forked, so as to admit the eye of the air-pump rod; and the pin which connects the two together is prolonged into a cross-head, as shown in fig. 112. The ends of this cross-head move in guides. The forked end of the connecting-rod is fixed upon the cross-head by means of a feather, so that the cross-head partakes of the motion of the connecting-rod, and a cap, similar to that attached to the piston-rod, is attached to the air-pump rod, for connecting it with the cross-head. This cap is shown in fig. 113. The diameter of the air-pump rod is 1½ inch, the external diameter of the socket encircling the rod is 2⅛ inches, and

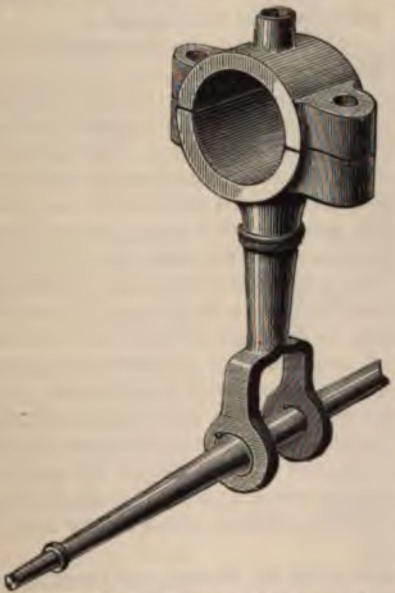


Fig. 112.—Air-pump Connecting-rod and Cross-head. Messrs. Penn.

the depth of the socket $4\frac{1}{2}$ inches from the centre of the cross-head. The depth of the cutter for attaching the socket to the rod is 1 inch, and its thickness $\frac{5}{16}$ inch. The breadth of the lugs is $1\frac{3}{8}$ inch, the depth $1\frac{1}{4}$ inch, making a total depth of $2\frac{1}{2}$ inches; and the diameter of the bolts $\frac{7}{8}$ of an inch. The diameter of tne cross-head at the centre is 2 inches, the thickness of each jaw around the bearing 1 inch, and the breadth of each $\frac{9}{16}$ inch. It is clear that, when a trunk is introduced into the air-pump, the cross-head and guides will not be required.

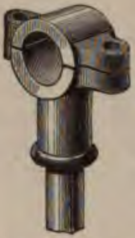


Fig. 113.—Cap of Air-pump Rod. Messrs. Penn.

Q. What are the dimensions of the crank-shaft and cranks?

A. The diameter of the intermediate shaft journal is $4\frac{3}{16}$ inches, and of the paddle-shaft journal $4\frac{3}{8}$ inches; the length of the journal in each case is 5 inches. The diameter of the large eye of the crank is 7 inches, and the diameter of the hole through it is $4\frac{3}{8}$ inches; the diameter of the small eye of the crank is $5\frac{1}{4}$ inches, the diameter of the hole through it being 3 inches. The depth of the large eyes is $4\frac{1}{4}$ inches, and of the small eye $3\frac{3}{4}$ inches; the breadth of the web is 4 inches at the shaft end, and 3 inches at the pin end, and the thickness of the web is $2\frac{5}{8}$ inches. The width of the notch forming the crank in the intermediate shaft for working the air-pump is $3\frac{1}{2}$ inches, and the width of each of the arms of this crank is $3\frac{15}{16}$ inches. Both the outer and inner corners of the crank are chamfered away, until the square part of the crank meets the round of the shaft. The method of securing the crank-pins into the crank eyes of the intermediate shaft consists in the application of a nut to the end of each pin, where it passes through the eye, the projecting end of the pin being formed with a thread upon which the nut is screwed.

Q. Will you describe the eccentric and eccentric-rod?

A. The eccentric and eccentric-rod are shown in fig. 114. The eccentric is put on the crank-shaft in two halves, joined in the diameter of largest eccentricity by means of a single bolt passing through lugs on the central eye, and the back balance is made in a separate piece $\frac{5}{8}$ of an inch thick, and is attached by means of two bolts, which also help to bind the halves of the eccentric together. The eccentric strap is $\frac{1}{2}$ an inch thick, and $1\frac{1}{4}$ inch broad, and the flanges of the eccentric, within which the strap works, are each $\frac{3}{8}$ of an inch thick. The eccentric-rod is attached to the eccentric-hoop by means of two bolts passing through lugs upon the rod, and tapped into a square boss upon the hoop; and pieces of iron, of a greater or less thickness, are interposed between the surfaces in setting the valve, to make the eccentric-rod of the right length. The eccentric-rod is kept in gear by the push of a small horizontal rod, attached to a vertical blade-spring, and it is thrown out of gear by means of the ordinary disengaging apparatus, which acts in opposition to the spring, as, in cases where the eccentric-rod is not vertical, it acts in opposition to the gravity of the rod.

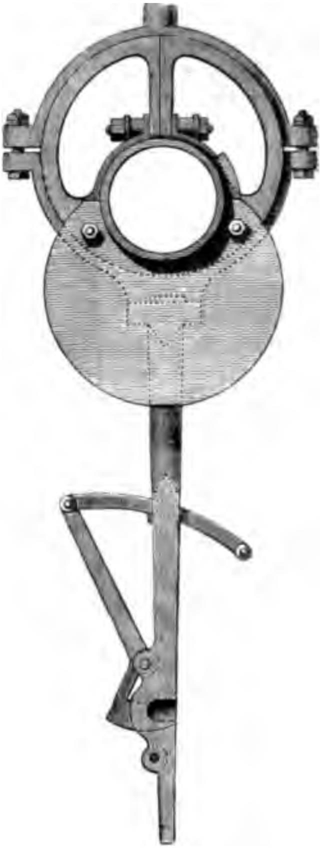


Fig. 114.—Eccentric and Rod. Messrs. Penn.

Q. Will you explain in detail the construction of the valve gearing, or such parts of it as are peculiar to the oscillating engine?

A. The eccentric-rod is attached by a pin, 1 inch in diameter, to an open curved link or sector, with a tail projecting upwards and passing through an eye to guide the link in a vertical motion. This sector, together with the valve lever-shaft, and finger for moving the valve, are represented in fig. 115. The link is formed of iron, case-hardened, and is $2\frac{3}{4}$ inches deep at the middle, and $2\frac{3}{8}$ inches deep at the ends, and 1 inch broad. The opening in the link, which extends nearly its entire length, is $1\frac{5}{16}$ inch broad; and into this opening a brass block, 2 inches long, is truly fitted, there being a hole through the block, $\frac{3}{4}$ inch diameter, for the reception of the pin of the valve-shaft lever. The valve-shaft is $1\frac{3}{4}$ inch diameter at the end next the link or segment, and diminishes regularly to the other end; but its cross-section assumes the form of an octagon in its passage round the cylinder, measuring mid-way $1\frac{1}{4}$ inch deep, by about $\frac{3}{4}$ inch thick, and the greatest depth of the finger for moving the valve is about 1 inch. The depth of the lever for moving the valve-shaft is 2 inches at the broad and $1\frac{1}{4}$ inch at the narrow end. The internal breadth of the mortice in which the valve-finger moves is $\frac{5}{16}$ inch, and its external depth is $1\frac{3}{4}$ inch, which leaves $\frac{3}{8}$ of an inch as the thickness of metal round the hole; and the breadth, measuring in the direction of the hole, is $1\frac{1}{8}$ inch. The valve rod is $\frac{3}{4}$ of an inch in diameter, and the mortice is connected to the valve-rod by a socket 1 inch long, and $1\frac{1}{8}$ inch diameter, through which a small cutter passes. A continuation of the rod, $\frac{11}{16}$ of an inch diameter, passes upward from the mortice, and works through

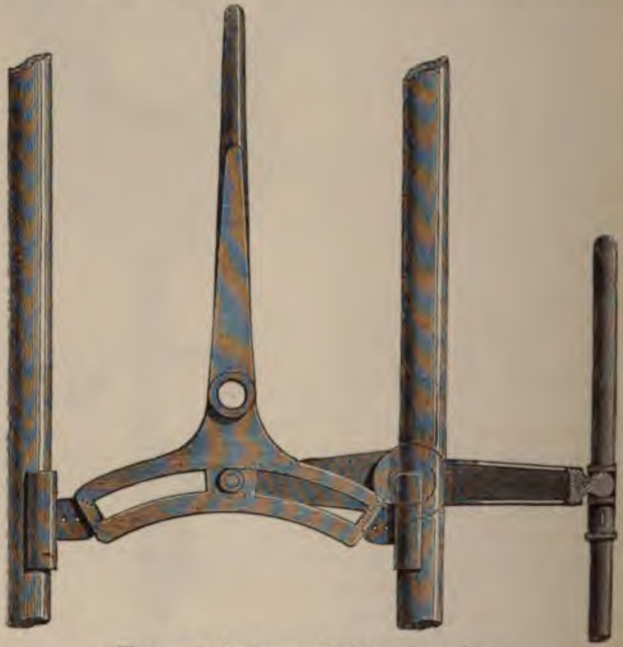


Fig. 115.—Valve Sector and Shaft. Messrs. Penn.

an eye, which serves the purpose of a guide. In addition to the guide afforded to the segment by the ascending tail, it is guided at the ends upon the columns of the framing by means of thin semi-circular brasses, 4 inches deep, passing half-round the columns, and attached to the segment by two ⅜-inch bolts at each end, fixed to projecting feathers upon the brasses and segment, ⅜ of an inch in thickness. The curvature of the segment is such as to correspond with the arc swept from the centre of the trunnion to the centre of the valve lever-pin when the valve is at half-stroke as a radius; and the operation of the segment is to prevent the valve from being affected by the oscillation of the cylinder. But the same action would be obtained by the employment of a smaller eccentric with more lead. In some engines the segment is not formed in a single piece, but of two curved blades, with blocks interposed at the ends, which may be filed down a little, to enable the sides of the slot to be brought nearer, as the metal wears away. Where two valves are used to each cylinder they are placed as nearly under the eccentric as they can be got, so that each is worked from the sweep shown in fig. 115 by a short ever, the brass block being made a little longer to permit two attachments instead of one.

Q. What kind of plummer blocks are used for the paddle-shaft bearings?

A. The paddle-shaft plummer blocks are altogether of brass, and are formed in much the same manner as the cap of the piston-rod, only that the sole is flat, as in ordinary plummer blocks, and is fitted between projecting lugs of the framing, to prevent side motion. In the bearings fitted on this plan, however, the upper brass will generally acquire a good deal of play after some amount of wear. The bolts are worked slack in the holes, though accurately fitted at first; and it appears expedient, therefore, either to make the bolts very large, and the sockets through which they pass very deep, or to let one brass fit into the other.

Q. How are the trunnion plummer blocks made?

A. The trunnion plummer blocks are formed in the same manner as the crank-shaft plummer blocks; the nuts are kept from turning back by means of a pinching screw passing through a stationary washer. It is not expedient to cast the trunnion plummer blocks upon the lower frame, as is sometimes done; for the cylinders, being pressed from the steam trunnions by the steam, and drawn in the direction of the condenser by the vacuum, have a continual tendency to approach one another; and as they wear slightly towards midships, there would be no power of re-adjustment unless the plummer blocks were movable. The flanges of the trunnions should always fit tight against the plummer block sides, but there should be a little play sideways at the necks of the trunnions, so that the cylinder may be enabled to expand when heated, without throwing an undue strain upon the trunnion supports.

Q. What kind of paddle-wheel is supplied with these oscillating engines?

A. The wheels are of the feathering kind, 9 feet 8 inches in diameter, measuring to the edges of the floats; and there are 10 floats upon each wheel, measuring 4 feet 6 inches long each, and 18½ inches broad. There are two sets of arms to the wheel, which converge to a cast-iron centre, formed like a short pipe with large flanges, to which the arms are affixed. The diameter of the shaft where the centre is put on is 4½ inches, the external diameter of the pipe is 8 inches, and the diameter of the flanges is 20 inches, and their thickness 1¼ inch. The flanges are 12 inches asunder at the outer edge, and they partake of the converging direction of the arms. The arms are 2¼ inches broad, and ½ an inch thick; the heads are made conical, and each is secured into a recess upon the side of the flange by means of three bolts. The ring which connects together the arms runs round at a distance of 3 feet 6 inches from the centre, and the projecting ends of the arms are bent backward the length of the lever which moves the floats, and are made very wide and strong at the point where they cross the ring, to which they are attached by four rivets. The feathering action of the floats is accomplished by means of a pin fixed to the interior of the paddle-box, set 3 inches in advance of the centre of the shaft, and in the same horizontal line. This pin is encircled by a cast-iron collar, to which rods are attached 1⅜ inch diameter in the centre, proceeding to the levers, 7 inches long, fixed on the back of the floats in the line of the outer arms. One of these rods, however, is formed of nearly the same dimensions as one of the arms of the wheel, and is called the driving arm, as it causes the cast-iron collar to turn round with the revolution of the wheel, and this collar, by means of its attachments to the floats, accomplishes the feathering action. The eccentricity in this wheel is not sufficient to keep the floats in the vertical position, but in the position between the vertical and the radial. The diameter of the pins upon which the floats turn is 1⅜ inch, and between the pins and paddle-ring a stud rod is set between each pair of the projecting ends of the arms, so as to prevent the two sets of arms from being forced nearer or drawn further apart, and thus prevent the ends of the arms from hindering the action of the floats by being accidentally jammed upon the sides of the joints. Stays, crossing one another, proceed from the inner flange of the centre to the outer ring of the wheel, and from the outer flange of the centre to the inner ring of the wheel, with the view of obtaining greater stiffness. The floats are formed of plate iron, and the whole of the joints and joint pins are steeled, or formed of steel. For sea-going vessels the most approved practice is to make the joint pins of brass, and to bush the eyes of the joints with *lignum vitæ;* and the surface should be large, to diminish wear.

Q. Can you give the dimensions of any other oscillating engines?

A. In Messrs. Penn's 50 nominal horse-power oscillating engine, the diameter of the cylinder is 3 feet 4 inches, and the length of the stroke 3 feet. The thickness of the metal of the cylinder is 1 inch, and the thickness of the cylinder bottom is 1¾ inch, crossed with feathers, to give it additional stiffness. The diameter of the trunnion bearings is 1 foot 2 inches, and the breadth of the trunnion bearings 5½ inches. Messrs. Penn, in their larger engines, generally make the area of the steam trunnion less than that of the eduction trunnion, in the proportion of 32 to 37; and the diameter of the eduction trunnion is regulated by the internal diameter of the eduction pipe, which is about $\frac{1}{8}$th of the diameter of the cylinder. But a somewhat larger proportion than this appears to be expedient. Messrs. Rennie make the area of their eduction pipes, in oscillating engines, $\frac{1}{22}$nd of the area of the cylinder. In the oscillating engines of the 'Oberon,' by Messrs. Rennie, the cylinder was 61 inches diameter, and 1½ inch thick above and below the belt, but in the wake of the belt it was 1¼ inch thick, which was also the thickness of metal of the belt itself. The internal depth of the belt was 2 feet 6 inches, and its internal breadth was 4 inches. The piston-rod was 6¾ inches in diameter, and the total depth of the cylinder stuffing-box 2 feet 4 inches, of which 18 inches consisted of a brass bush—this depth of bearing having been employed to prevent the stuffing-box or cylinder from wearing oval.

Q. Can you give any other examples?

A. The diameter of cylinder of the oscillating engines of the steamers 'Pottinger,' 'Ripon,' and 'Indus,' by Miller and Ravenhill, was 76 inches, and the length of the stroke 7 feet. The thickness of the metal of the cylinder was $1\frac{11}{16}$ inch; diameter of the piston rod, $8\frac{3}{4}$ inches; total depth of cylinder stuffing-box, 3 feet; depth of bush in stuffing-box, 4 inches; the rest of the depth, with the exception of the space for packing, being occupied with a very deep gland, bushed with brass.

Q. Is it the invariable practice to make the piston-rod cap of brass in the way you have described?

A. In all oscillating engines of any considerable size, the cover of the connecting brass, which attaches the crank-pin to the connecting-rod, is formed of malleable iron; and the socket also, which is cuttered to the end of the piston-rod, is of malleable iron, and is formed with a T head, through which bolts pass up through the brass, to keep the cover of the brass in its place.

Q. Is the piston of an oscillating engine made deeper than in common engines?

A. It is expedient, in oscillating engines, to form the pist with a projecting rim round the edge above and below, and a corresponding recess in the cylinder cover and cylinder botto whereby the breadth of bearing of the solid part of the metal will be increased, and in many engines this is now done.

Q. Would any difficulty be experienced in keeping the trunnions tight in a high-pressure oscillating engine?

A. It is very doubtful whether the steam trunnions of a high pressure oscillating engine would continue long tight if the packin consists of hemp; and it appears preferable to introduce a bra ring to embrace the pipe, cut spirally, with an overlap piece cover the cut, and packed behind with asbestos.

Q. How is the packing of the trunnions usually effected?

A. The packing of the trunnions, after being plaited as as possible, and cut to the length to form one turn round the is dipped into boiling tallow, and is then compressed in a r consisting of two concentric cylinders, with a gland forced into the annular space by three to six screws in the case o diameters, and one central screw in the case of small di Unless the trunnion packings be well compressed, they likely to leak air, and it is, therefore, necessary to pay attention to this condition. It is also very importan nions be accurately fitted into their brasses by s that there may not be the smallest amount of play left upon them; for if any upward motion is permitted, it will be impossible to prevent the trunnion packings from leaking.

Q. What kind of boilers have usually been employed to work oscillating and other paddle-engines?

A. They have generally been square tubular boilers, whether the power has been great or small. The 'Great Eastern,' the largest steam vessel hitherto constructed, and which was propelled both by paddles and by a screw, was fitted with boilers of this character, as will be seen by a reference to fig. 116, where one of these boilers is represented. In all steamers, whether paddle or screw, before the introduction of the compound system, boilers of this class were employed. The necessary strength to prevent rupture or bulging was got by introducing numerous stays, extending from top to bottom and from side to side of the boiler. In the 'Great Eastern' the paddle-engines were oscillating, and the screw-engines were direct-acting horizontal; but both alike drew their steam from the same class of boilers, of which there were ten.

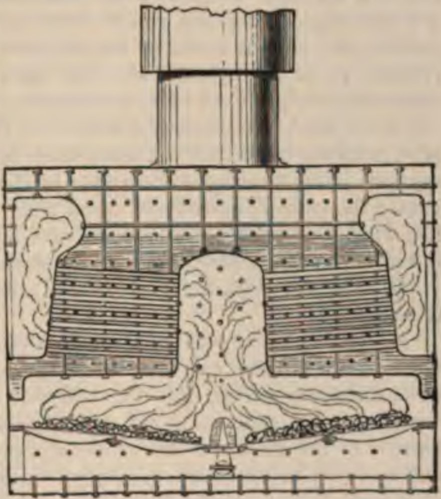


Fig. 116.—Boilers of Steamer 'Great Eastern.' By Boulton, Watt, and Co.

DIRECT-ACTING HORIZONTAL SCREW-ENGINES.

Q. Having described an oscillating paddle-engine in minute detail, will you now describe in similar detail a direct-acting horizontal engine?

A. I will take as an example of this species of engine the engine constructed by Messrs. John Bourne and Co. for the screw-steamer 'Alma,' a vessel of 500 tons burden. This engine was a single steeple engine laid on its side. The cylinder was of 42 inches diameter and 42 inches stroke, and the vessel was propelled by this single engine at the rate of 14 miles an hour.

Q. Is not a single engine liable to stick upon the centre, so that it cannot be started or reversed with facility?

A. A single engine is no doubt more liable to stick upon the centre than two engines, the cranks of which are set at right angles with one another. But numerous paddle-vessels are propelled by a single engine, and the screw offers still greater facility than paddles for such a mode of construction. In the screw-engine referred to, as the cylinder was laid upon its side, there was no unbalanced weight to be lifted every stroke; and the crank, whereby the screw-shaft was turned, consisted of two discs with a heavy side, intended to balance the momentum of the piston and its connections. But these counter-weights by their gravitation also prevented the connecting-rod and crank from continuing in the same line when the engine was stopped, and, in fact, placed the crank in the most advantageous position for starting again.

Q. Will you explain the general arrangement of the parts of this engine?

A. The cylinder was laid on its side near one side of the vessel, and from the cylinder two piston-rods extended to a cross-head sliding, in guides, near the other side of the vessel. To this cross-head the connecting-rod was attached, and one end of it partook of the motion of the cross-head or piston, while the other end was free to follow the revolution of the crank on the screw shaft, and, in fact, rotated it.

Q. What is the advantage of two discs entering into the composition of the crank instead of one?

A. A double crank, such as two discs form with the crank-pin, is a much steadier combination than would result if only one disc were employed with an overhung pin. Then the friction on the neck of the shaft is made one-half less by being divided between the two bearings, and the short prolongation of the shaft beyond the journal is convenient for the attachment of the eccentrics to work the valves.

Q. Was the cylinder of the usual strength and configuration?

A. The cylinder was formed of cast iron in the usual way, and was 1⅛ inch thick in the barrel. The ends were of the same thickness, but were each stiffened with six strong feathers. The piston was cast open. The bottom of it was ⅝ths of an inch thick, and it was stiffened by six feathers ¾ of an inch thick; but the feather connecting the piston-rod eyes for the reception of the two piston-rods was 1¼ inch thick, and the metal round the eyes was 2 inches thick. The piston was closed by a disc or cover, ⅝ths of an inch thick, secured by 15 bolts, and this cover answered also the purpose of a junk-ring. The piston packing consisted of a single cast-iron ring, 3½ inches broad and ½ inch thick, packed behind with hemp. This ring was formed with a tongue-piece, with an indented plate behind the cut; and the cut was oblique, to prevent a ridge forming in the cylinder. The total thickness of the piston was 5½ inches. The piston-rods were formed with conical ends for fitting into the piston, but were coned the reverse way as in locomotives, and were secured in the piston by nuts on the ends of the rods, these nuts being provided with ratchets to prevent them from unscrewing accidentally.

Q. What species of slide-valve was employed?

A. The ordinary three-ported valve, and it was set on the upper side of the cylinder. The cylinder ports were 4½ inches broad by 24 inches long; and to relieve the valve from the great friction due to the pressure on so large a surface, a balance piston was placed over the back of the valve, to which it was connected by a strong link; and the upward pressure on this piston being nearly the same as the downward pressure on the valve, it followed that the friction was extinguished, and the valve could be moved with great ease by one hand. The balance piston was 21 inches in diameter. In the original construction of this balance piston two faults were committed. The passage communicating between the condenser and the top of the balance piston was too small, and the pins at the ends of the link connecting the valve and balance piston were formed with an inadequate amount of bearing surface. It followed from this misproportion that the balance piston, being adjusted to take off nearly the whole of the pressure, lifted the valve off the face at the beginning of each stroke. For the escape of the steam into the eduction passage momentarily impaired the vacuum subsisting there, and owing to the smallness of the passage leading to the space above the balance piston, the vacuum subsisting in that space could not be impaired with equal rapidity. The balance piston, therefore, rose by the upward pressure upon it momentarily predominating over the downward pressure on the valve; but this fault was corrected by enlarging the communicating passage between the top of the balance piston and the eduction pipe. The smallness of the pins at the ends of the link connecting the valve and balance piston caused the surfaces to cut into one another, and to wear very rapidly. The pins and eyes in this situation should be large in diameter, and as long as they can be got, as they are not so easily lubricated as the other bearings about the engine, and are, moreover, kept at a high temperature by the steam. The balance piston was packed in the same way as the main piston of the engine. Its cylinder was only a few inches in length.

Q. What was the diameter of the piston-rod and connecting-rod?

A. The piston-rods, which were two in number, were 3 inches diameter, and 12 feet 10 inches long over all. The connecting-rod consisted of two rods, which were prolongations of the bolts that connected the sides of the brass bushes which encircled the crank-pin and cross-head. The connecting-rod is shown in perspective in fig. 117. The rods composing it were each 2¾ inches in diameter.

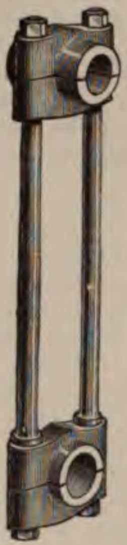


Fig. 117.—Connecting-rod. Messrs. Bourne and Co.

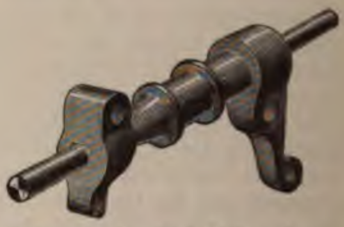


Fig. 118.—Cross-head and Pump Arms. Messrs. Bourne and Co.

Q. Will you describe the configuration of the cross-head?

A. The cross-head, exhibited in fig. 118, was a round piece o iron like a short shaft, with two unequal arms keyed upon it, th longer of which worked the air-pump, and the shorter the fee pump. The piston-rods entered these arms at the points wh the larger holes are shown, one of these rods passing above the other beneath the crank-shaft. The cross-head was 8 in diameter where it was embraced by the connecting-rod, and 7 inches diameter where the air-pump and feed-pump arms were fixed on. The ends, for a length of 12 inches, were reduced to 3 inches diameter where they fitted into round holes in the guide blocks. Those blocks were of cast iron 6 inches deep, 11 inches wide, and 14 inches long.

Q. Will you recapitulate the main particulars of the air-pump?

A. The air-pump was made of brass, 12½ inches diameter and 42 inches stroke, and the metal of the barrel was $\frac{9}{16}$ths of an inch thick. The air-pump bucket was a solid piston of brass, 6½ inches deep at the edge, and 7 inches deep at the eye; and in the edge three grooves were turned to hold water, which answers the purpose of packing. The inlet and outlet valves of the air-pump were formed with brass plates, ½ inch, with strong feathers across them, and in each plate there were six grated perforations or grids covered by indiarubber discs, 7 inches in diameter. These six perforations afforded collectively an area for the passage of the water equal to the area of the pump. The air-pump rod was of brass, 2½ inches diameter.

Q. What were the constructive peculiarities of the discs and crank-pin?

A. The discs, which were 64 inches diameter, were formed of cast iron, 2½ inches thick in the body, and 5 inches broad at the rim. The crank-shaft was 8½ inches diameter, and the central boss of the disc which received the shaft measured 10 inches through the eye. The metal of the eye was 3 inches thick. In the part of the disc opposite to the crank-pin, the web was thickened to 10 inches for nearly the whole semicircle, with the view of making that side of the disc heavier than the other side; and when the engine was stopped, the gravitation of this heavy side raised the crank-pin to the highest point it could attain, whereby it was placed in mid-stroke. The crank-pin was 8½ inches diameter, and the length of the bearing or rubbing part of it was 16 inches. It was secured at the ends to the discs by flanges 18 inches diameter and 2 inches thick. These flanges were indented into thickened parts of the discs, and were each attached to its corresponding disc by six bolts 2 inches diameter, countersunk in the back of the disc, and tapped into the malleable iron flange. Besides this attachment, each end of the pin, reduced to 4½ inches diameter, passed through a hole in its corresponding disc, and the ends of the pin were then riveted over. The crank-pin was perforated through the centre by a small hole about ¾ of an inch in diameter, and a perforation proceeded from this central hole to the surface of the pin. Each crank-shaft bearing was similarly perforated, and pipes were cast in the discs connecting these perforations together. The result of this arrangement was that a large part of the oil or water fed into the bearings of the shaft was driven by the centrifugal action of the discs to the surface of the crank-pin, and in this way the crank-pin was oiled or cooled wit water in a very effectual manner. To intercept the water or o which the discs thus drove out by their centrifugal action, a ligh

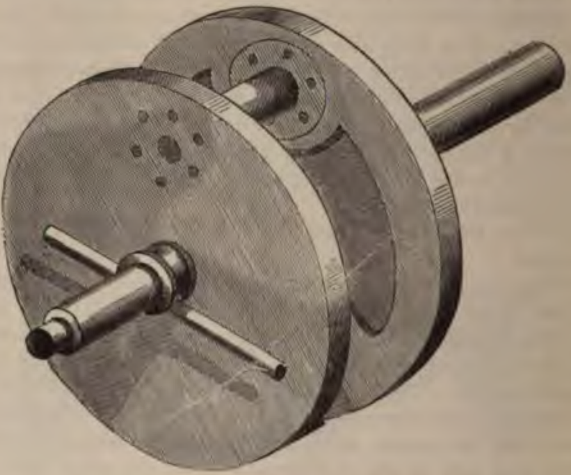


Fig. 119.—Double Disc Crank. Messrs. Bourne and Co.

paddle-box or splash-board of thin sheet-brass was made to cover the upper part of each of the discs.

Q. What was the diameter of the screw-shaft?

A. The screw-shaft was 7½ inches diameter, but the bearin on each side of the disc were 8½ inches diameter, and 16 inch long. Between the side of the disc and the side of the contigu bearing there was a short neck extending 4¾ inches in the le of the shaft, and hollowed out somewhat to permit the passa the piston-rod. As already stated, one piston-rod passed i diately above the shaft on the one side of the discs, and the piston-rod passed immediately below the shaft on the other side of the discs. A short piece of one piston-rod is shown in fig. 119.

Q. How was the thrust of the screw-shaft received?

A. The thrust of the screw-shaft was received upon 7 collars, each 1 inch thick, and with 1 inch of projection above the shaft. The plummer block for receiving the thrust of the shaft is shown in fig. 120, and the coupling to enable the screw-propeller to be disconnected from the engine, so that it might revolve freely when the vessel was under sail, is shown in fig. 121. When it was required to disengage the propeller from the engine, the pins passing through the opposite eyes, shown in fig. 121, were withdrawn by means of screws provided for that purpose, and the propeller and the engine were thenceforth independent of one another.

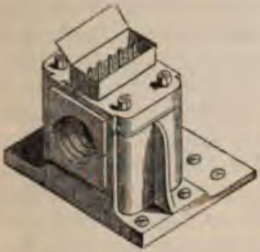


Fig. 120.—Thrust-bearing.
Messrs. Bourne and Co.

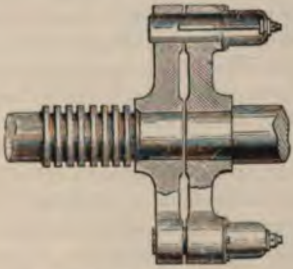


Fig. 121.—Coupling Cranks.
Messrs. Bourne and Co.

MODERN COMPOUND MARINE ENGINES.

Q. Are modern compound marine engines generally of the horizontal or vertical type?

A. They are sometimes horizontal, and Messrs. Penn have made some of their horizontal trunk-engines on the compound principle for war vessels. But for commercial vessels compound engines are almost invariably of the vertical type, with the cylinders inverted, and for war vessels also compound engines are now largely constructed on the same plan.

Q. Will you give an example of such engines embodying the most recent improvements?

A. I will select for this purpose the engines of the 'Cristoforo

Colombo,' as they have the special feature of interest that they can be worked either as ordinary engines or as compounds. This vessel is a cruiser of the Royal Italian Navy. The engines were designed and constructed in 1875 by Messrs. John Penn and Sons to meet the wishes of the naval authorities, who desired to have for this vessel engines of limited weight which should be able to work with great economy at low powers, but should be capable of exerting a considerably increased power when required. The engines are formed with three cylinders, of the uniform diameter of 62 inches and with a length of stroke of 3 feet 3 inches. They can exert 4,000 indicated horse-power at full speed by the direct admission of steam direct from the boilers into all three cylinders, but, by a simple arrangement of stop-valves, when half-power or less suffices, the steam is admitted direct into only one cylinder, which then becomes a high-pressure cylinder, and is thence dismissed into the other two cylinders, which act as low-pressure cylinders. The engine, as thus arranged, becomes a three-cylinder compound engine of the usual type. In this way is obtained an engine which, though lighter than a compound engine worked at full power, has all the economical advantages of a compound engine at the moderate speeds at which vessels of war generally cruise, while it is able when necessary, at some sacrifice of economy, temporarily to exert a very high power and to impart a very high speed. The engines of the 'Cristoforo Colombo' are shown in fig. 122, from which the general nature of the arrangement will be readily comprehended.

Q. Of what kind are the boilers?

A. There are 8 boilers of the ordinary cylindrical type, 12 feet in diameter, supplying steam at 60 lbs. pressure. The surface condenser is fixed in the wing of the ship, the water being circulated by a centrifugal pump worked by a separate engine. The air-pump, as is the usual arrangement in vertical engines, is worked by a lever moved by the piston-rod. All the cylinders are steam-jacketed, and have independent expansion gear.

Q. Was this form of engine found to give satisfactory results?

A. The 'Cristoforo Colombo' was so successful that the same type of engine was adopted by the Italian Government for several other of their ships of war, notably for the two large ironclads 'Italia' and 'Lepanto,' intended each to exert 18,000 indicated horses-power. The plan has also been adopted by the British Admiralty for the ironclads 'Northampton,' 'Agamemnon,' and 'Ajax,' and by the Spanish Government for several cruisers. In the latter case the engines were horizontal instead of vertical.

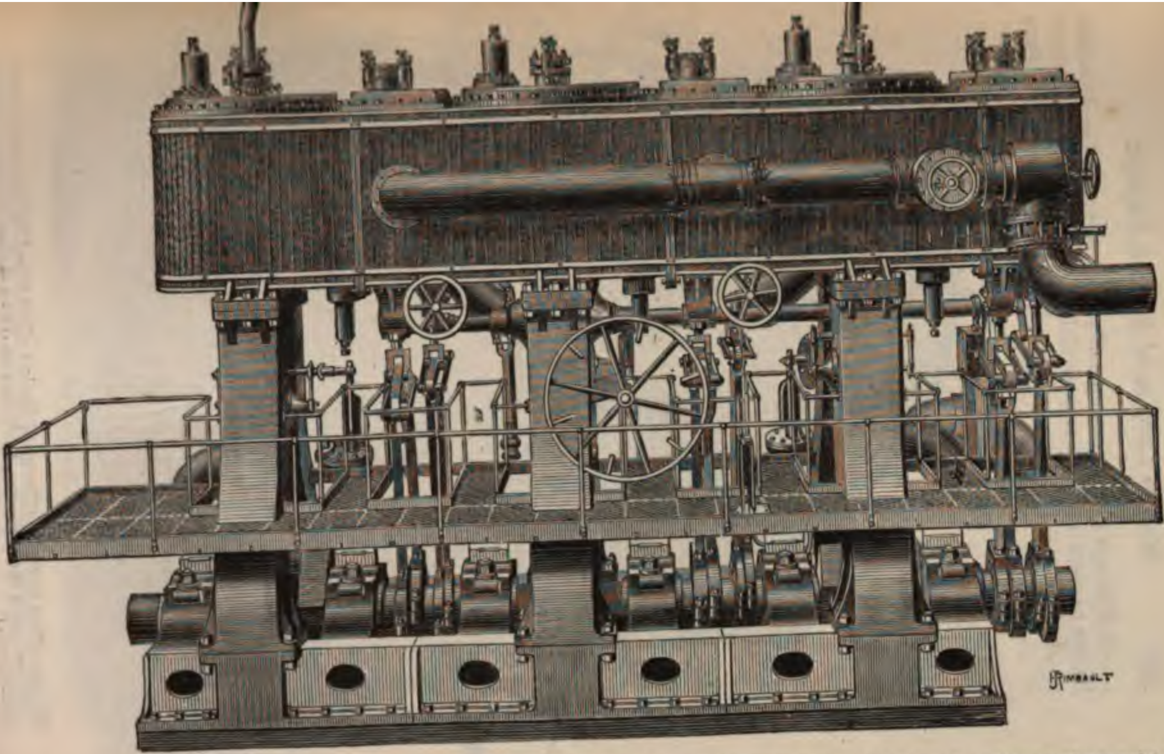


Fig. 122.—Inverted Compound Engines of the Italian Cruiser 'Cristoforo Colombo.' By Messrs. John Penn and Sons, 1875. (From a photograph.)

Q. Will you give an example of marine compound engines and boilers as constructed for commercial purposes at the present time?

A. I will describe the main features of the engines and boilers

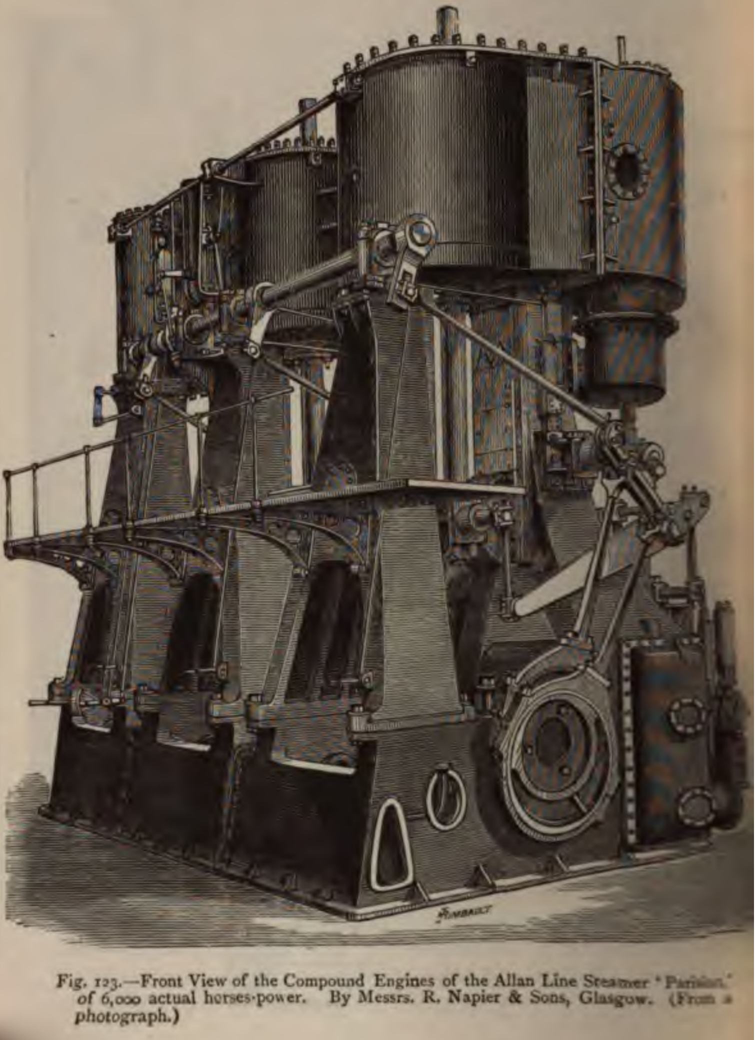


Fig. 123.—Front View of the Compound Engines of the Allan Line Steamer "Parisian," of 6,000 actual horses-power. By Messrs. R. Napier & Sons, Glasgow. (From a photograph.)

constructed by Messrs. R. Napier and Sons, of Glasgow, for the 'Parisian,' one of the steamers of the Allan line between Liverpool and Montreal. Although the engines have three cylinders and

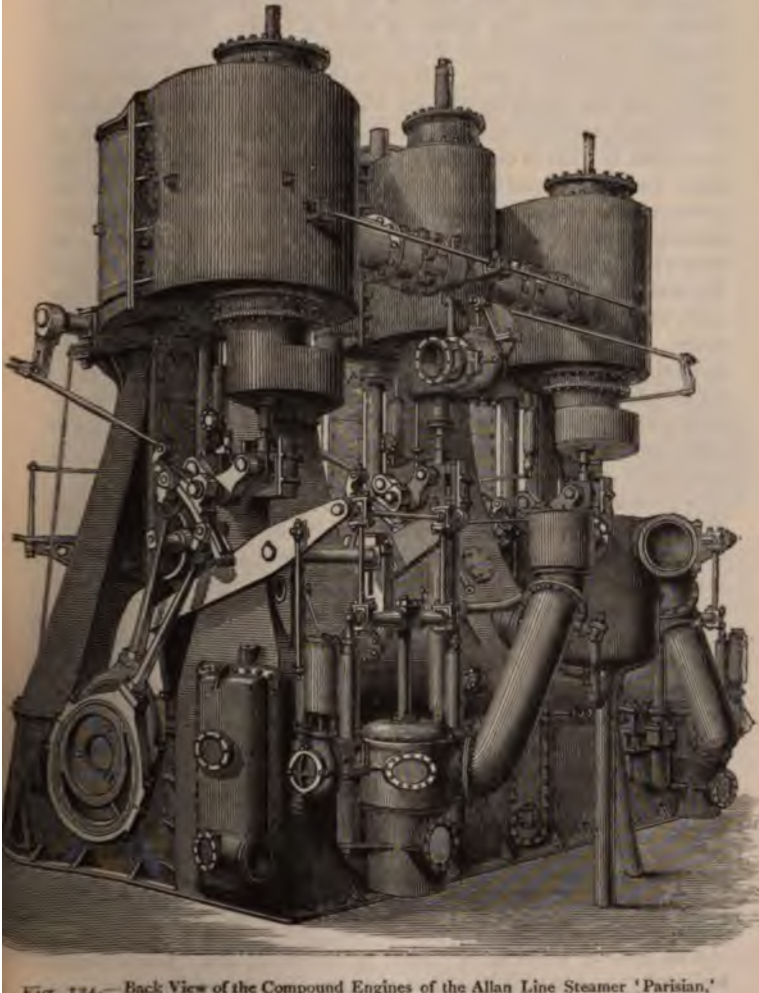


Fig. 224.—Back View of the Compound Engines of the Allan Line Steamer 'Parisian,' of 6,000 actual horses-power. By Messrs, R. Napier and Sons, Glasgow. (From a photograph.)

three cranks, they are ordinary compound engines, expanding the steam in two successive steps in the usual manner. The low-pressure cylinder is, as it were, cut in two. The high-pressure cylinder is 60 inches diameter, and each of the low-pressure cylinders is 85 inches diameter. The stroke of each is 5 feet. The crank-shaft is made up of three single throw-cranks, coupled together by couplings with 9 bolts in each, and the cranks are placed at 120° apart. This shaft was made by Messrs. Vickers entirely of steel, the body of the shaft and the crank-pin being shrunk into the eyes; in fact, the crank is what is commonly known as a built crank. For large sizes and a moderate length of stroke, these cranks are, in the present state of the steel manufacture, preferable to solid forgings, although heavier, as the machinery for working steel seems to be scarcely equal to the production of solid cranks of such dimensions. By making the shaft in three pieces, each of which is interchangeable, one single piece of crank-shaft is quite sufficient to carry as spare. The cylinders have all of them separate working barrels, jointed with a flange at the bottom, and packed with asbestos pasteboard at the top, thus forming a steam-jacket and an expansion joint. The pistons are of cast iron. The piston-rods are of steel, carried through stuffing-boxes on the cylinder covers. A front view of the engines is given in fig. 123.

Q. Of what kind are the slide-valves?

A. The three slide-valves are each of them piston-valves, worked by ordinary link motions, but with the intervention of a bent lever, partly to change the direction of the motion, and partly to change the travel of the valves, which from being piston-valves are almost of necessity single-ported. To save space the eccentrics are keyed on the shaft couplings. A back view of the engines is given in fig. 124. It is, perhaps, needless to say that all the shaft bearings are lined with white metal.

Q. What were the particulars of the 'Great Eastern's' machinery?

A. Four paddle-engines, each 74 inches diameter and 14 feet stroke, and four screw-engines, each 84 inches diameter and 4 feet stroke. Four boilers, each 17 feet 9 inches long, 17 feet 6 inches wide, and 13 feet 9 inches high, to furnish steam for paddle-engines, and six similar for screw-engines. Each boiler contained 400 brass tubes, 3 inches diameter and 5½ feet long, giving about 44,000 square feet of heating surface. Pressure of steam, 25 lbs. Each boiler weighed 55 tons, and held 45 tons of water. Number of furnaces, 112.

Q. Of what kind is the thrust-bearing?

A. The thrust-shaft was forged by Messrs. Vickers of steel, and is of the kind commonly known as a horse-shoe thrust, as the thrust is taken upon a number of adjustable pieces upon which the collars press. In this variety the lower part of the collar does not bear, and is free to lick up the oil or oil and water which is placed in the lower part of the cast-iron trough beneath the bearing. Each of the collars is separately adjustable, and any of them could even be taken out while the engines were at work. The configuration of the parts of the thrust-bearing will be understood by a reference to fig. 125, where A is the thrust-shaft, B the seating in which it works, carrying the horse-shoe pieces, one of which is shown at C. An ordinary shaft plummer block is shown at D. These horse-shoes were cast of steel and faced with white metal on the bearing surface, a zigzag oil groove being formed on the face of each to enable the oil to enter more easily.

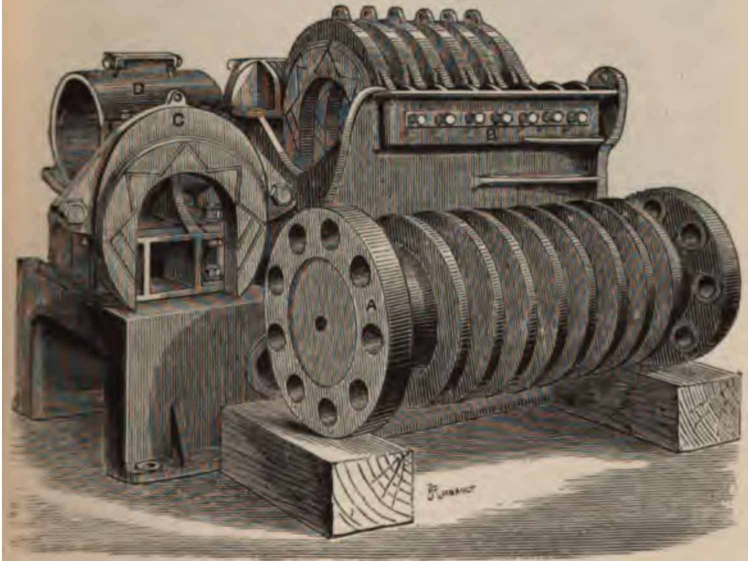


Fig. 125.—Parts of the Thrust-bearing of the Allan Line Screw-steamer 'Parisian,' of 6,000 actual horses-power. By R. Napier and Sons, Glasgow. (From a photograph.)

Q. Will you next describe the boilers?

A. The boilers, four in number, with 6 furnaces in each, are made of iron for a pressure of 75 lbs. per square inch. The diameter of each barrel is 15 feet 4½ inches, and the length is 17 feet 9 inches. The diameter of the furnaces is 3 feet 9 inches inside. The grate surface is 540 square feet, and the heating surface 15,176 square feet. On trial the indicated horses-power was fully 6,000, and at sea the mean horse-power is very close on 5,000 regularly.

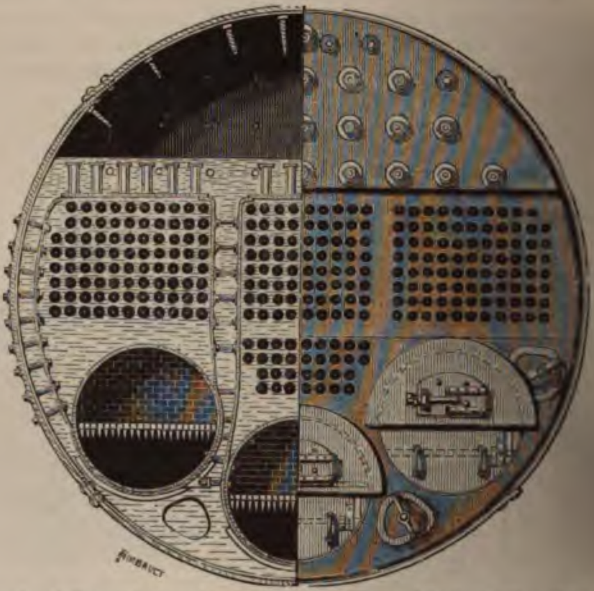


Fig. 126.—Half Front View and Half Cross-section of one of the four Boilers of the Allan Line Screw-steamer 'Parisian,' of 6,000 actual horses-power. By R. Napier and Sons, Glasgow.

Q. Is not this a high average to maintain?

A. It is only in a trade like the North American one that such a high horse-power can be kept up throughout the voyage. For this trade the machinery requires to be of a very strong character, and very carefully kept in repair. The runs are short; like a locomotive, the ship may be said to be in the repairing shed every week. Thus the machinery can be kept in a state of efficiency, quite equal to what it was when new. If we compare this performance with sea-going work in long voyages of 40 days or thereby in crossing the Equator, we shall find that the average power, instead of being kept up to ⅚ths of the maximum trial performance, can scarcely be kept up to ¾ths, and oftener only to ⅔rds.

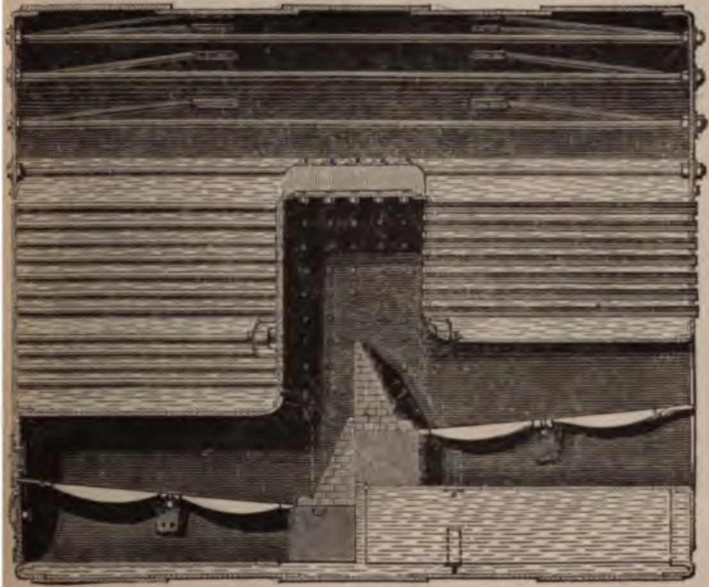


Fig. 127.—Longitudinal Section of one of the four Boilers of the Allan Line Screw-steamer 'Parisian,' of 6,000 actual horses-power. By R. Napier and Sons, Glasgow.

Q. Is not the 'Alaska' reckoned one of the most efficient steamers upon the Atlantic?

A. She is generally so regarded.

Q. Can you give any information to illustrate the cause of her high speed?

A. The cause is not far to seek. It is the natural result of her great power.

Q. Is there anything peculiar in the plan of boiler?

A. No; the boilers are of the type usual for working compound engines. But there are nine of them ; they are of steel, and carry a pressure of 100 lbs. on the square inch.

Q. Will you describe the structure of one of these boilers?

A. Its configuration is shown in figs. 128 and 129, where A A are the furnaces ; B B, the furnace bridges ; C, one of the furnace doors ; D, the tube-plate ; and E the uptake which conducts the smoke from the furnace into the tubes, whence it ascends the chimney. The furnaces, it will be observed, are corrugated. This greatly strengthens them against collapse, and at the same time obviates any considerable longitudinal strain from unequal expansion caused by unequal heating. The boilers are each 15 feet in diameter and 17 feet 4 inches long. The total heating surface in the nine boilers is 35,000 square feet, and the total grate surface is 12,000 square feet.

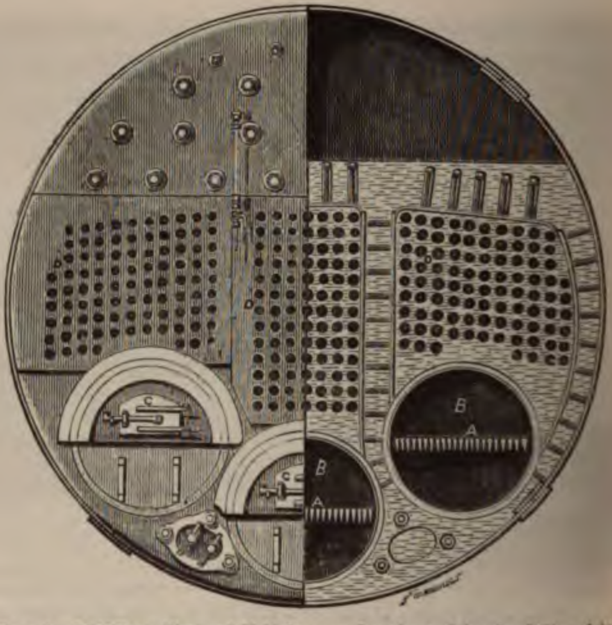


Fig. 128.—Half Front View and Half Cross-section of one of the nine Boilers of the Screw-steamer 'Alaska.' By John Elder and Co., Glasgow.

Q. How many actual horses-power should these boilers generate?

A. Nearly 12,000 horses-power. In modern marine boilers using the steam expansively an actual horse-power is produced with an allowance of 3 square feet of heating surface in the boiler and 2 square feet of cooling surface in the condenser.

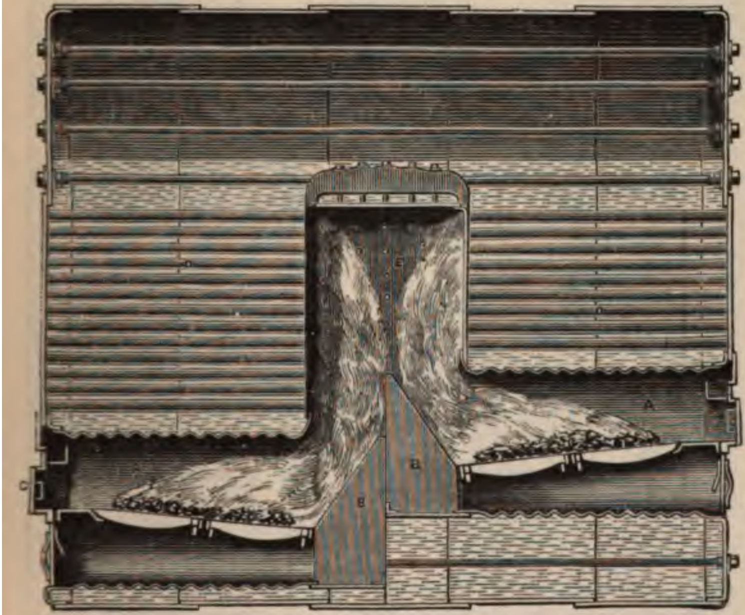


Fig. 129.—Vertical Longitudinal Section of one of the nine Boilers of the Screw-steamer 'Alaska.' By John Elder and Co., Glasgow.

Q. Is this the maximum performance that is possible?

A. By no means. There is a resource still practically unapplied in sea-going vessels which would greatly increase their power—the employment of an artificial draught in the stoke-hole, such as has long been used by Ericsson and others in America and which has been successfully introduced by Thorneycroft and others in this country in the case of torpedo-boats. Such a system, however, is equally applicable to ordinary sea-going steamers, and must come into use.

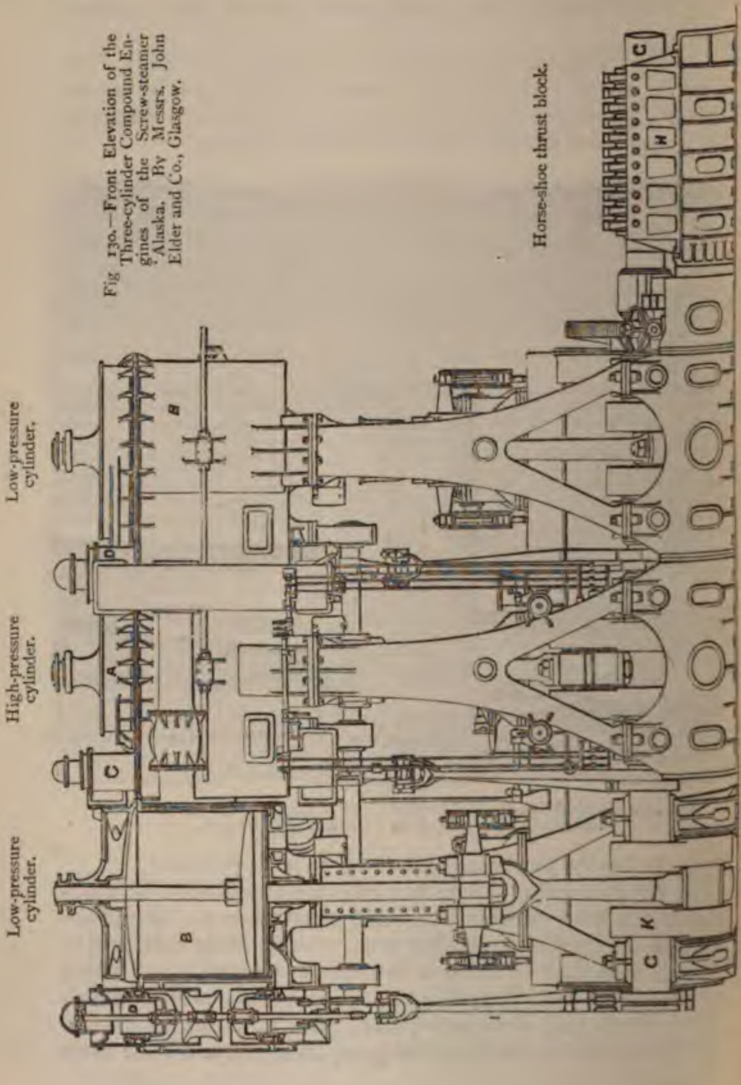


Fig 130.—Front Elevation of the Three-cylinder Compound Engines of the Screw-steamer 'Alaska.' By Messrs. John Elder and Co., Glasgow.

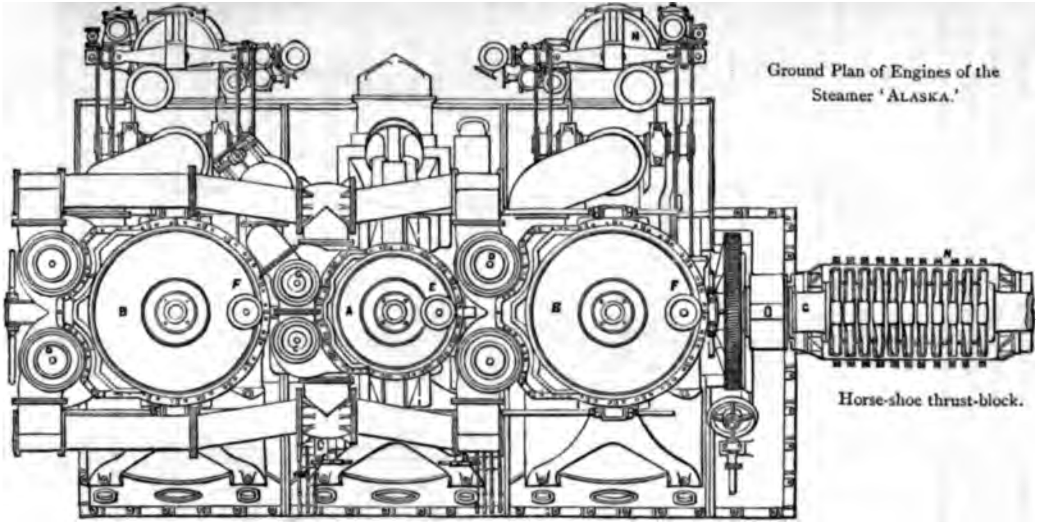


Fig. 131.—Ground Plan of the Three-cylinder Compound Engines of the Screw-steamer 'Alaska.'
By Messrs. John Elder and Co., Glasgow.

Q. Are the engines of the 'Alaska' of the compound type?

A. Yes, and they are shown in front elevation in fig. 130, in plan in 131, and in end elevation in 132. The engines have three inverted cylinders—one high-pressure cylinder, 68 inches diameter and 6 feet stroke in the middle, and two low-pressure cylinders, each 100 inches diameter and 6 feet stroke at the sides, the two acting as one cylinder. All the slide-valves are of the equilibrium piston description. The surface condensers are arranged to form part of the engines, with two separate centrifugal circulating pumps placed at the back of the engines. Fig. 130 shows the three cylinders and their connections, also the thrust-block at the after

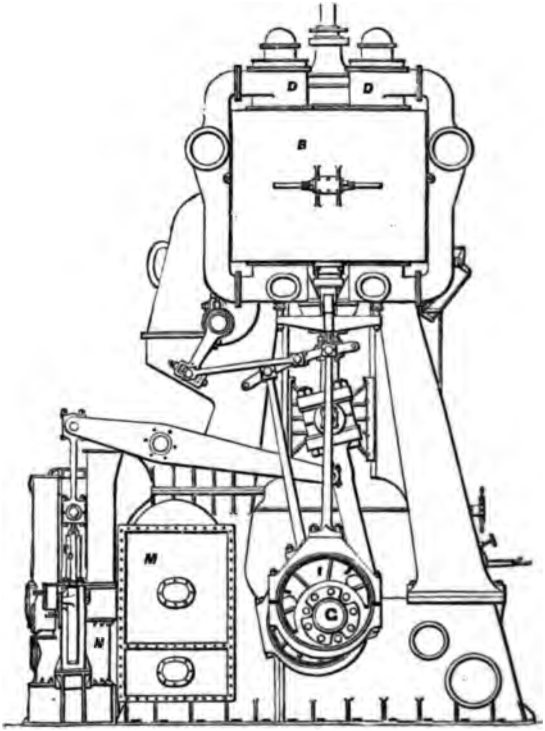


Fig. 132.—End Elevation of one of the Engines of the Three-cylinder Compound Engines of the Screw-steamer 'Alaska.' By Messrs. John Elder and Co., Glasgow.

end of the engines, which, it will be seen, is similar to that of the 'Parisian.' In this view the forward low-pressure cylinder is shown in section, also one of the piston slide-valves and the main shaft-bearings. The end elevation shows the position of the condenser with the air, feed, and bilge-pumps at the back; also the arrangement of the gear for working the slide-valves. The plan of the engines shows the relative positions of the cylinders, the piston slide-valves, the air, feed, and bilge-pumps. The centrifugal circulating pumps are not shown. There are two of them, each worked by a small engine.

Q. Will you describe the position of the different parts with the aid of letters of reference?

A. The high-pressure cylinder is shown at A and the two low-pressure cylinders at B B. The high-pressure engine slide-valve is shown at C, and the low-pressure piston slide-valves at D D. The high-pressure cylinder escape-valve will be seen at E on the plan, and the low-pressure escape-valves at F F. G is the main shaft, H the thrust-bearing, and K the cranks. I represents the eccentrics; M, the condenser; N, the air-pump; O, the feed-pumps; and close thereto the bilge-pumps. The same letters refer to the same parts in all the figures. The 'Alaska' was built and her engines and boilers were constructed by Messrs. John Elder and Co., of Glasgow, for Messrs. Guion and Co., of Liverpool, to ply between Liverpool and New York. The machinery is exceptionally strong, on account of the exceptionally severe work it has to perform.

Q. Are the engines and boilers used in torpedo-boats similar to those employed in ocean steamers?

A. The engines are similar, though of much smaller size, but the boilers are more of the locomotive type. The engines have been brought to a high degree of perfection, but there is still trouble caused by the boilers, especially from priming and from the leakage of the tubes at the ends.

Q. Will you describe the structure of the boiler of a first-class torpedo-boat?

A. This will be best illustrated by the aid of a drawing. In figs. 133 and 134 such a boiler is shown, where A is the furnace; B, the bridge; C, the tubes; D, longitudinal stays; E, vertical stays from furnace-crown to shell; F, furnace door.

Q. As the engines are condensing, there can be no blast-pipe in the chimney, such as exists in locomotives. How, then, is the necessary draught maintained?

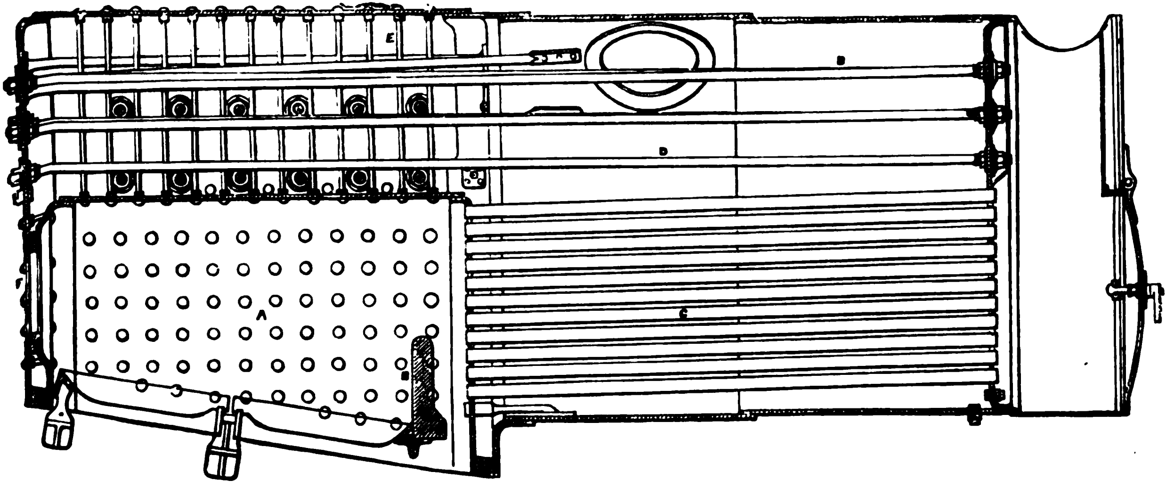


Fig. 133.—Longitudinal Section of the Boiler of a First-class Torpedo Boat. By Messrs. Thorneycroft and Co. (Scale, ½ inch = 1 foot.)

A. The stoke-hole is close, and the air necessary for combustion is forced into it by a fan. The pressure of air is such as to balance from two to six inches of water. The boiler is made flat on the top to give more steam room, which is rendered necessary by the steam being taken away less continuously than in a locomotive. But the same end would be gained by using a large steam-pipe to serve as a reservoir, and by working with the regulator very much closed. A boiler of this kind for a first-class torpedo-boat will weigh about five tons empty, and the water will weigh about two tons. The total weight of the machinery will be about twice the weight of the boiler and water.

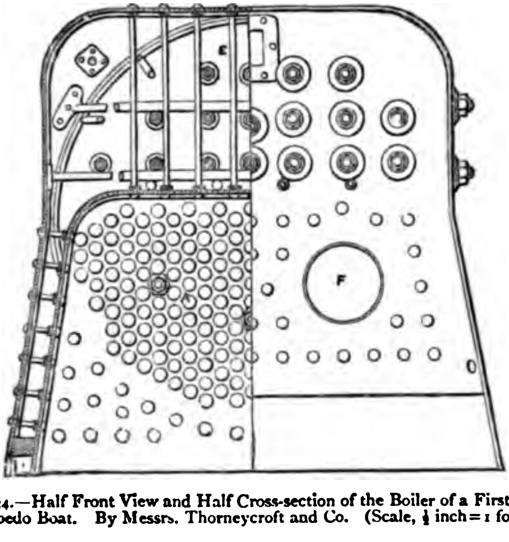


Fig. 134.—Half Front View and Half Cross-section of the Boiler of a First-class Torpedo Boat. By Messrs. Thorneycroft and Co. (Scale, ¾ inch = 1 foot.)

Q. What are the main proportions of this boiler?

A. The total area of heating surface is 620 square feet, of which 56 square feet are fire-box surface. The area of grate is 18·4 square feet. The barrel is 4 feet 5 inches diameter, and 12 feet 6 inches long. It contains 205 tubes, 5 feet long and 1¾ external diameter. The working pressure is 120 lbs. per square inch.

Q. What were the main facts of this boiler's performance with different pressures of air in stoke-hole?

A. The boiler was carefully tried under steam at Portsmouth. The results obtained are shown in the following table :—

Boiler Trials, First-class Torpedo Boat.

Air-pressure in stoke-hole . . .	inches	2	3	4	6
,, ash-pit	,,	1·47	2·29	3·26	5·25
,, furnace	,,	1·35	1·87	3·0	4·33
Temperature, feed-water . . .	Fahr.	53·5	57	54	56
,, funnel	,,	1,073	1,192	1,260	1,444
Steam-pressure (above atmosphere) .	lbs.	117	117	115	115
Coal consumed per hour	,,	925	1,177	1,472	1,815
,, per square foot of fire-grate	,,	49	62	78	96
Water evaporated per hour	,,	6,530	7,770	9,320	10,840
,, per lb. of coal . .	,,	7·06	6·6	6·33	5·97
Evaporation per lb. of coal reduced to equivalent at 212° F. from 100° .	.	7·61	7·08	6·81	6·41
Evaporation per hour in lbs. per square foot of heating surface	.	10·8	12·9	15·5	18·0
Coal used, Nixon's Navigation.					
Ashes, 9 per cent.		H. M.	H. M.	H. M.	H. M.
Duration of experiment	.	2 0	2 7	1 39	1 27

Q. Will you now describe the engines?

A. The engines, which are of the usual inverted compound type, are shown in figs. 135, 136, and 137; fig. 135 being an end elevation of the engines with the high-pressure cylinder nearest the spectator, fig. 136 a vertical longitudinal section of the engines, and fig. 137 an elevation with the low-pressure cylinder in front.

Q. Will you give some further particulars of the vessel and the engines?

A. The boat is 87 feet long, with a breadth of beam of 10½ feet. The draught of water is 1 foot 6 inches forward, and 3 feet 2 inches aft, with a displacement of 32·4 tons. The high-pressure cylinder is 12¾ inches diameter, and the low-pressure 20⅛ inches, and the stroke of both is 12 inches. The cranks are at right angles, and there is an intermediate receiver. The refrigerating water is sent through the condenser tubes by a centrifrugal pump, worked by a separate engine. The slide-valves have the pressure taken off by being set under bridges, which will lift if there be undue internal pressure. The packing-rings of the pistons are of Perkins' metal, four in each piston in separate grooves. This metal works without lubrication. Two feed-pumps are worked by a cast-iron four-thread worm on the screw shaft-gearing into a wheel of phosphor bronze, having cranks at the ends, to each of which a feed-pump is attached.

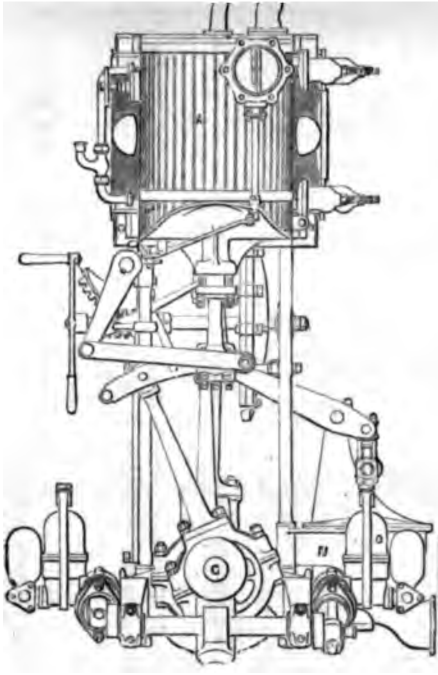


Fig. 135.—End Elevation of Engines of First-class Torpedo Boat (High-pressure Cylinder in front). By Messrs. Thorneycroft and Co.

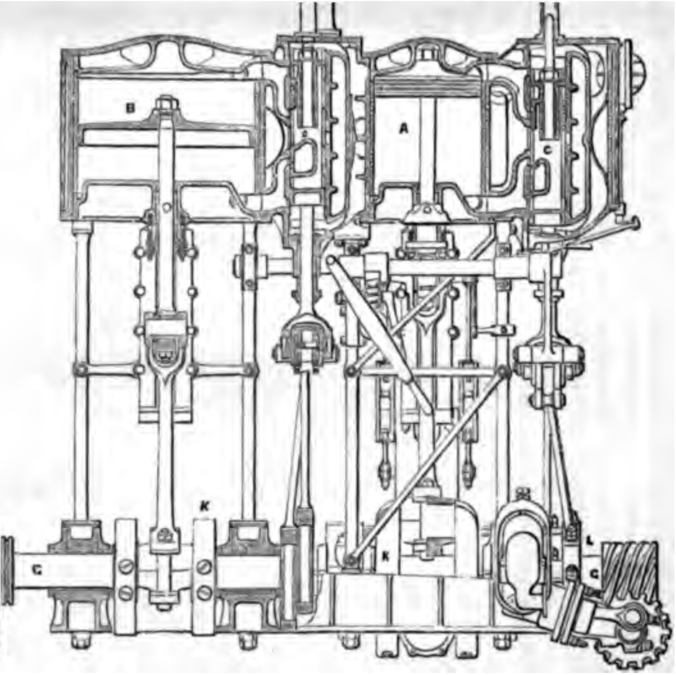


Fig. 136.—Vertical Longitudinal Section of Engines of First-class Torpedo Boat (Low pressure Cylinder in front). By Messrs. Thorneycroft and Co.

The feed-pumps are 4 inches diameter, with a 3-inch stroke. The propeller is 4 feet 6 inches diameter, formed with three blades, and with a pitch of 6 feet. The screw is in this case set before the rudder, but behind it is a better position.

Q. Will you, by the aid of letters of reference, specify the different parts of the engine?

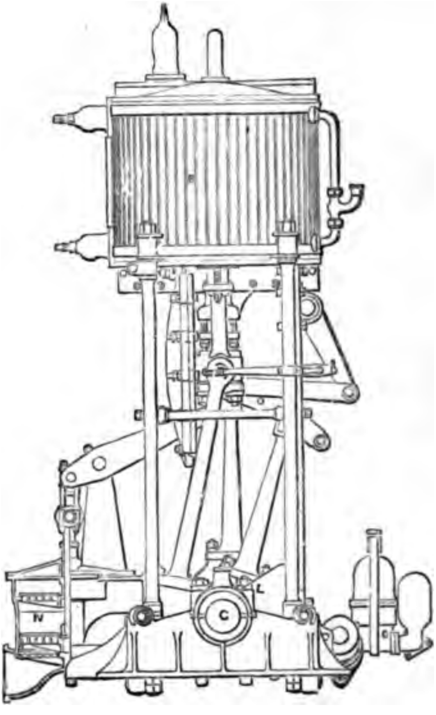


Fig. 137.—End Elevation of Engines of First-class Torpedo Boat (Low-pressure Cylinder in front). By Messrs. Thorneycroft and Co.

A. That can be easily done. A is the high-pressure and B the low-pressure cylinder; C is the high-pressure slide-valve, and D the low-pressure slide-valve; G, crank-shaft; K K, cranks; L eccentrics; N, air-pump; and O, feed-pump.

Q. Have you anything to suggest in regard to the efficacy of these torpedo-boats?

A. Nothing, except in regard to the boiler, by which trouble continues to be given. There would probably be less priming if the engines were to be simple engines working expansively instead of compounds, as there would thus be twice as many deliveries of steam by the boiler in the same time, and by this expedient the same immunity from priming would be obtained that is got in locomotives, while the efficacy would be in no way diminished in other respects. Messrs. Thorneycroft originally made their fire-boxes of copper and their tubes of brass, but had to introduce iron in consequence of the brass and copper of the fire-box and tubes expanding more than the iron of the shell, which caused the tubes to start at the ends. But by corrugating the boiler shell its rigidity would be so far reduced as to accommodate any inequality of expansion, and the use of copper and brass, which in conducting power are much superior to iron, could thus be resumed. A greater length of tube could also thus be employed.

Q. With the diameter of screw you have given, the stern-frame must project below the bottom of the boat if the screw be wholly immerged?

A. Yes, that is the case, and the whole screw works below the surface. The stern-frame is forged of Bessemer steel, with an elliptical cross-section to reduce its resistance to a minimum.

Q. In modern marine engines and boilers what is the weight per actual horse-power?

A. In merchant vessels it is very generally about 480 lbs. In the navy it was a few years ago about 420 lbs., subsequently reduced to 360 lbs. But a very considerable reduction of the weight has quite recently been obtained by the introduction of an artificial blast. In the 'Polyphemus,' fitted with a close stoke-hole into which the air is driven by fans, the weight of the machinery is 180 lbs. per actual horse-power. Thorneycroft's torpedo boat machinery weighs just ⅓ of this, or 60 lbs. per horse-power. An express locomotive, if cleared of wheels, springs, buffers, buffer-beams, and other parts which do not concern the power of the engine proper, but merely enable it to run upon a railway, will weigh little, if anything, more than the Thorneycroft engine. Such a locomotive, with 18-inch cylinders, 24 inches stroke, and 1,200 square feet of heating surface, will weigh about 21 tons, and with a piston speed of 1,000 to 1,200 feet per minute will exert about 800 actual horses-power. Supposing that the weight of machinery could be still further reduced to 45 lbs. per actual horse-power, which in the case of large engines appears probable, then 45,000 horse-power of machinery could be kept within a weight of 900 tons. In the case of a vessel of the same displacement as the 'Iris,' or 4,200 tons, it has been reckoned that a speed of 40 knots would be obtained with 45,000 actual horses-power. At this speed the distance between Galway and Halifax could be accomplished in 42 hours. Taking the coal consumed at 2 lbs. per actual horse-power per hour, the coal consumed on the voyage would be 1,680 tons, and, making a little allowance for a reserve, the coal required to be carried may be taken at 1,900 tons, the actual consumption being about 40 tons per hour. The machinery and coal would therefore weigh 2,800 tons, leaving a displacement of 1,400 tons for the weight of the hull, stores, and provisions. It seems highly probable that a service of very light and swift boats will be organised for carrying mails and passengers across the Atlantic, and also upon other important lines, and in these vessels a prime condition of success will be to keep down the weight. In a torpedo-boat 100 feet long it was found that the speed fell off a quarter of a knot for each additional ton carried. The strain on the steel piston-rods, main bolts, &c., is 6,000 lbs. per square inch of section, and upon the steel plates of the boilers 8,300 lbs. per square inch of section. With strict attention to the quality of the material, these proportions are quite safe. A cubic foot of water is evaporated by the boiler per hour for every three square feet of heating surface. With these proportions a good deal of the heat will go up the chimney, but a very light boiler is got, and this is the more important consideration in such a case.

MODERN LOCOMOTIVES.

Q. You have already given a general description of the locomotives brought together at the Paris Exhibition of 1867. Will you now give a more detailed and practical description of a locomotive of about that epoch?

A. The locomotives referred to may be taken as fairly representative of the bulk of the locomotives in use at the present time, except that locomotives are now generally fitted to burn coal, though it cannot be said that the arrangements employed for that purpose are of a very perfect character.

Q. Will you first describe the more important details of one particular engine as made about that date, and subsequently describe some of the smoke-burning arrangements which have since been employed?

A. I will take for this purpose the locomotive 'Snake,' constructed by John V. Gooch for the London and South Western Railway, as an example of a locomotive of good average construction, adapted for the narrow gauge. The length of the wheel base of this engine is 12 feet 8½ inches. There are two cylinders, each 14¼ inches diameter and 21 inches stroke. The total weight of the engine is 19 tons; and this weight is so distributed on the wheels as to throw 8 tons on the leading wheels, 6 tons on the driving wheels, and 5 tons on the hind wheels. The engine is made with outside cylinders, and the cylinders are raised somewhat out of the horizontal line to enable them better to clear the leading wheels.

Q. What are the dimensions of the boiler?

A. The interior of the fire-box is 3 feet 7¼ inches wide by 3 feet 5½ inches long, measuring in the direction of the rails. The area of the fire-grate is consequently 12·4 square feet. The bars are somewhat lower on the side next the fire-door than at the side next the tubes, and the mean height of the crown of the fire-box above the bars is 3 feet 10 inches. The top edge of the fire-door is about 7 inches lower than the crown of the fire-box. The fire-box is divided transversely by a corrugated feather or bridge of plate-iron, containing water, abcut 3½ inches wide, and of about ⅓ of the height of the fire-box in the centre of the feather, and about ⅔ the height of the fire-box at the sides where it joins the sides of the fire-box. The internal shell of the fire-box tapers somewhat upwards to facilitate the disengagement of the steam. It is about 2 inches narrower at the top than at the bottom and shorter; the water space between the external and internal shell of the fire-box being 2 inches at the bottom and 3 inches at the top.

Q. Of what material is the fire-box composed?

A. The external shell of the fire-box is formed of iron plates ⅜ths of an inch thick, and the internal shell is formed of copper plates ½ inch thick, but the tube-plate is ¾ inch thick. The fire-grate is rectangular, and the internal and external shells are tied together by iron stay-bolts ¾ inch diameter, and pitched about 4 inches apart. The roof of the fire-box is stiffened by six strong bars extending from side to side of the fire-box like beams, and the top of the fire-box is secured to these bars, so that it cannot be forced down without breaking or bending them.

Q. What are the dimensions of the barrel of the boiler?

A. The barrel of the boiler is 3 feet 7$\frac{1}{2}$ inches in diameter, and 10 feet long. It is formed of iron plates $\frac{3}{8}$ths of an inch thick, riveted together. It is furnished with 181 brass tubes, 1$\frac{7}{8}$ inch diameter and 10 feet long, secured at the ends by ferrules. The tube-plate at the smoke-box end is $\frac{5}{8}$ths of an inch thick, and the tube-plates above the tubes are tied together by 8 iron rods $\frac{7}{8}$ths of an inch thick, extending from end to end of the boiler. The metal of the tubes is somewhat thicker at the end next the fire, being 13 wire gauge at fire-box end, and 14 wire gauge at smoke-box end. The rivets of the boiler are $\frac{3}{4}$ inch diameter and 1$\frac{1}{2}$ inch pitch. The plating of the ash-pan is $\frac{5}{16}$ths of an inch thick, and the plating of the smoke-box is $\frac{3}{16}$ths of an inch thick.

Q. Will you describe the structure of the framework on which the boiler and its attachments rest, and in which the wheels are set?

A. The framework or framing consists of a rectangular structure of plate-iron circumscribing the boiler, with projecting lugs or arms for the reception of the axles of the wheels. In this engine the sides of the rectangle are double, or, as far as regards the sides, there are virtually two framings, one for the reception of the driving axles, and the other for the reception of the axles not connected with the engine. The whole of the parts of the outer and inner framings are connected together by knees at the corners, and the double sides are elsewhere connected by intervening brackets and stays, so as to constitute the whole into one rigid structure. The whole of the plating of the inside frame is $\frac{3}{4}$ inch thick and 9 inches deep. The plating of the outside frame is of the same thickness and depth at the fore part, until it reaches abaft the position of the cylinders and guides, where it reduces to $\frac{1}{2}$ inch thick. The axle-guard of the leading wheels is formed of $\frac{3}{4}$ plate bolted to the frame with angle-iron guides. The axle-guards of the trailing wheels are formed of two $\frac{1}{2}$-inch plates, with cast-iron blocks between them to serve as guides. The ends of the rectangular frame are formed of plates $\frac{3}{4}$ inch thick, and at the front end there is a buffer-beam of oak, 4$\frac{1}{2}$ inches thick and 15 inches deep. The draw-bolt is 2 inches diameter. There are two strong stays on each side, joining the barrel of the boiler to the inside framing, and one angle-iron on each side, joining the bottom of the smoke-box to the inside framing.

Q. Of what construction are the wheels?

A. The wheels and axles are of wrought-iron, and the tires of the wheels are of steel. The driving wheels are 6 feet 6½ inches in diameter, and the diameter of crank-pin is 3½ inches. The diameter of the smaller wheels is 48½ inches. The axle-boxes are of cast-iron with bushes of Fenton's metal, and the leading axle has four bearings. The springs are formed of steel plates, 3 feet long, 4 inches broad, and ½ inch thick. The axle of the driving wheel has two eccentrics, forged solid upon it, for working the pumps.

Q. Will you specify the dimensions of the principal parts of the engine?

A. Each of the cylinders, which is 14¼ inches diameter, has the valve-casing cast upon it. The steam-ports are 13 inches long and 1⅝ inches broad, and the exhaust-port is 2½ inches broad. The travel of the valve is 4⅛ inches, the lap 1 inch, and the lead ¼ inch. The piston is 4 inches thick: its body is formed of brass with a cover of cast-iron, and between the body and the cover two flanges, forged on the piston-rod, are introduced to communicate the push and pull of the piston to the rod. The piston-rod is of iron, 2⅛ inches diameter. The guide-bars for guiding the top of the piston-rod are of steel, 4 inches broad, fixed to rib-iron bearers, with hard wood, ¼ of an inch thick, interposed. The connecting-rod is 6 feet long between the centres, and is fitted with bushes of white metal. The eccentrics are formed of wrought iron, and have 4⅛ inches of throw. The link of the link motion is formed of wrought iron. It is hung by a link from a pin attached to the framing; and instead of being susceptible of upward and downward motion, a rod connecting the valve-rod with the movable block in the link is susceptible of this motion, whereby the same result is arrived at as if the link were moved and the block was stationary. One or the other expedient is preferable, according to the general nature of the arrangements adopted. The slide-valve is of brass, and the regulator consists of two brass slide-valves worked over ports in a chest in the steam-pipe, set in the smoke-box. The steam-pipe is of brass, No. 14 wire gauge, perforated within the boiler barrel with holes $\frac{1}{12}$th of an inch in diameter along its upper side. The blast-pipe, which is of copper, has an orifice of 4¼ inches diameter. There is a damper, formed like a venetian blind, with the plates running athwartships at the end of the tubes.

Q. Of what construction is the safety-valve?

A. There are two safety-valves, consisting of pistons $1\frac{3}{16}$ inch in diameter, and which are kept down by spiral springs placed immediately over them. A section of this valve is given in fig. 138.

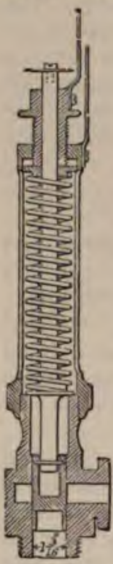


Fig. 138.—Safety Valve. By Gooch.

Q. What are the dimensions of the feed-pumps?

A. The feed-pumps are of brass, with plungers 4 inches diameter and 3¼ inches stroke. The feed-pipe is of copper, 2 inches diameter. A good deal of trouble has been experienced in locomotives from the defective action of the feed-pump, partly caused by the leakage of steam into the pumps, which prevented the water from entering them, and partly from the return of a large part of the water through the valves at the return stroke of the pump, in consequence of the valve lifting too high. The pet-cock—a small cock communicating with the interior of the pump—will allow any steam to escape which gains admission, and the air which enters by the cock when open cools down the barrel of the pump, so that in a short time it will be in a condition to draw. The most ordinary species of valve in the feed-pumps of locomotives is the ball-valve, represented in figs. 98 and 99, in which the lift is much less than was at one time usual. Fig. 99 is a section of a feed-pump, showing the ball-valves and plunger.

Notwithstanding the excellent performance of the best examples of locomotive engines, it is quite certain that there is still much room for improvement; and indeed various sources of economy are at present visible, which, if properly developed, would materially reduce the expense of the locomotive power. In all engines the great source of expense is the fuel; and although the consumption of fuel has been greatly reduced within the last thirty years, it is capable of being still further reduced by certain easy expedients of improvement, which therefore it is important should be universally applied. One of these expedients which has now been widely adopted consists in heating the feed-water by the waste steam; and the feed-water should in every case be sent into the boiler boiling hot. The ports of the cylinders should be as large as possible; the expansion of the steam should be carried to a greater extent; and in the case of engines with outside cylinders, and indeed in all locomotives, a little air should be forced into the boiler to mix with the steam. The escape of heat from the boiler should be more carefully prevented. The engine is now always balanced by weights on the wheels, to obviate a waste of power by yawing on the rails. A most important expedient of economy lies in the establishment of a system of registering the performance of all new engines, in order that competition may stimulate the different constructors to the attainment of the best possible result; and under the stimulus of comparison and notoriety, a large measure of improvement would speedily ensue. The benefits consequent on public competition are abundantly illustrated by the rapid diminution of the consumption of fuel in the case of agricultural engines, when this stimulus is presented. The particulars of the performance of these engines are detailed in the following chapter. It is quite indispensable that pressures of from 200 to 250 lbs. should be employed in locomotives, and it is material that as much work as possible should be got out of every engine, and that little time should be consumed in repairs.

Q. Will you describe the contemporaneous engine of the London and North Western Railway?

A. This engine is represented in fig. 139, where A is the safety-valves; B, the fire-box; C, the tubes; D, the driving axle; E, the link motion; F, the valve spindle; G, balance-weight of link motion; H, cylinder; J, buffer-beam. The following are the principal dimensions:—Diameter of cylinder, 16 inches; stroke, 24 inches; driving wheels, 7 feet 6 inches diameter; leading and trailing wheels, 3 feet 6 inches diameter; weight on leading wheels, 9 tons 8 cwt.; weight on trailing wheels, 6 tons 2 cwt.; weight on driving wheels, 10 tons 10 cwt.—total weight, 27 tons; heating surface of fire-box, 85 square feet; heating surface of 192 tubes, 1⅞ inch external diameter and 10 feet 9 inches long, 915 square feet (internal); total heating surface, 1,000 square feet. The distance of the leading from the driving wheels is 7 feet 7 inches, and the distance of the trailing from the driving wheels is 7 feet 10 inches—making the length of the wheel base 15 feet 5 inches. The tender carries 2 tons of coal and 1,500 gallons of water, and its weight laden is 17 tons 8½ cwt. It runs on six wheels of 3 feet 6 inches diameter. This form of express engine, designed by Mr. Ramsbottom, may be taken as representing the most approved form of construction in that class of locomotives in 1865. The arrangements are characterised by much simplicity and elegance;

RAMSBOTTOM'S EXPRESS PASSENGER LOCOMOTIVE.

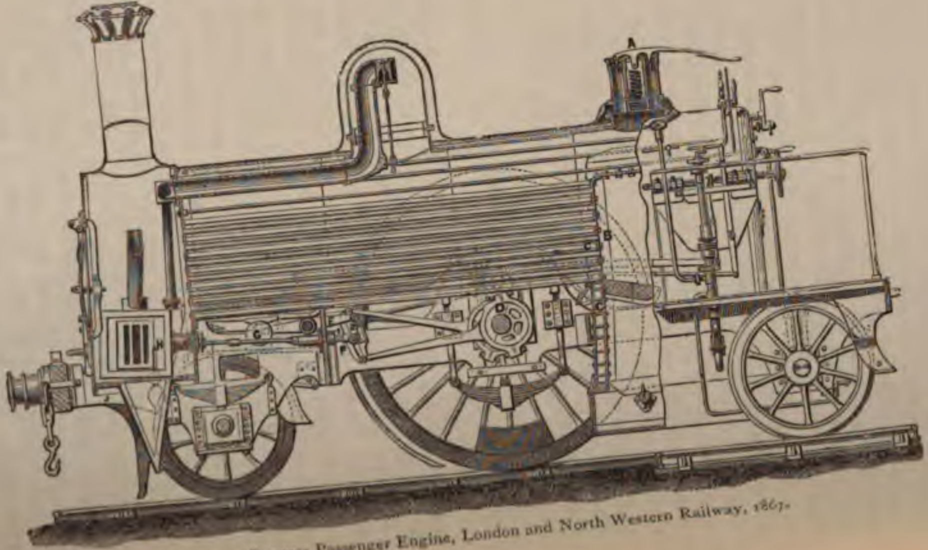


Fig. 139.—Express Passenger Engine, London and North Western Railway, 1867.

their nature is made so clear by the drawing that it is unneces-y further to describe them.

Q. Will you now describe some of the arrangements for enabling l to be burnt instead of coke?

A. One of the earliest and best arrangements is that known Tembrinck's, represented in fig. 140, which shows the fire-box of of the locomotives employed on the Paris and Orleans Railway, l in which Tembrinck's system of burning the smoke was many

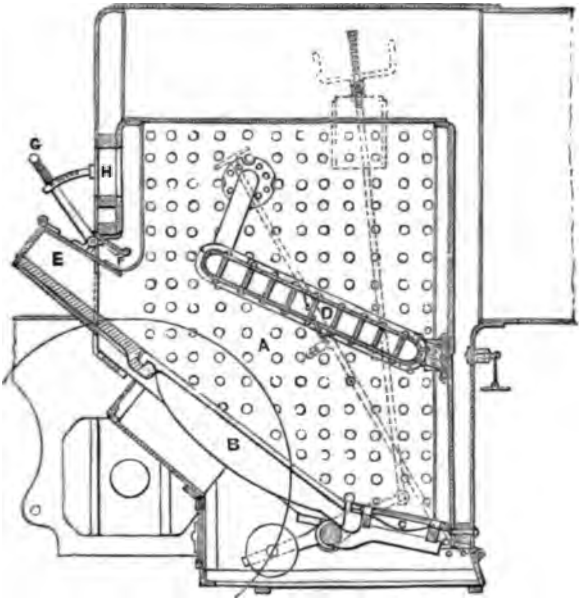


Fig. 140. Fire-box on Tembrinck's System.

rs since introduced. A is the fire-box in which the fire is ced, resting on the fire-bars B, and these bars are made taper, as to have a narrower air space near the furnace mouth than ther in; C is a set of subsidiary bars set in a frame, which may opened to drop the fire or to let the clinkers out; D is a water ce running obliquely across the furnace nearly parallel to the s; E is a mouthpiece to receive the coal which is there roasted the radiant heat from the fire; and the expelled gas is burned by coming into contact with the flame from the fire after being mixed with the air, which enters through the air-valve at F, which is regulated by the handle G ; H is one of the doors opening into the fire-box. It is stated that in these engines the evaporation with coal is about the same as with an equal weight of coke, and that the expense of the fuel is only half as great as when coke is employed.

Q. What other smoke-burning arrangements are there?

A. They are too numerous to specify. But there is very little originality in any of them, the arrangements employed having with little difference been already tried in stationary boilers, and having fallen into disuse from their imperfect performance. Cudworth's smoke-burning locomotive is shown in fig. 141. The fire-box is made very long, and is carried back over the hind axle; the fire-grate is inclined towards the tube-plate, and at the lower end it is furnished with a trap-door, through which the clinkers and ashes are discharged and the fire is dropped. The fire-door is perforated ; and air is admitted through it when necessary. A thin fire is kept on the grate. The fresh fuel is supplied at the upper end only, and it gradually descends during combustion, so that there is only a bright, clear fire at the lower end. The gases evolved from the fresh fuel, mixed with air passing through the grate and door, are sufficiently heated in their way to the tubes to inflame, and hence less smoke is made. It is one of the advantages of this engine that, owing to the fire-box projecting over the hind axle, the weight on the coupled wheels is increased and equalised. In fact, the weight of the engine is equally distributed over all the wheels.

Q. The principle of this smoke-burning arrangement is, in fact, the principle of the dead-plate introduced by Watt into his boilers in the last century?

A. Yes, and for stationary boilers where combustion does not require to be hurried it answers very well. But it does not appear to be the proper principle for locomotives. The principle of the blast furnace would, it seems to me, be much more appropriate.

Q. Have any attempts been made to introduce the compound system into the locomotive engine?

A. Yes, but so far no very conspicuous benefit has resulted. The benefits of the compound system, even in land and marine engines, have been greatly over-rated, as the economy derivable from the use of high-pressure steam worked expansively has been erroneously imputed to some inscrutable virtue of the compound

CUDWORTH'S COAL-BURNING LOCOMOTIVE.

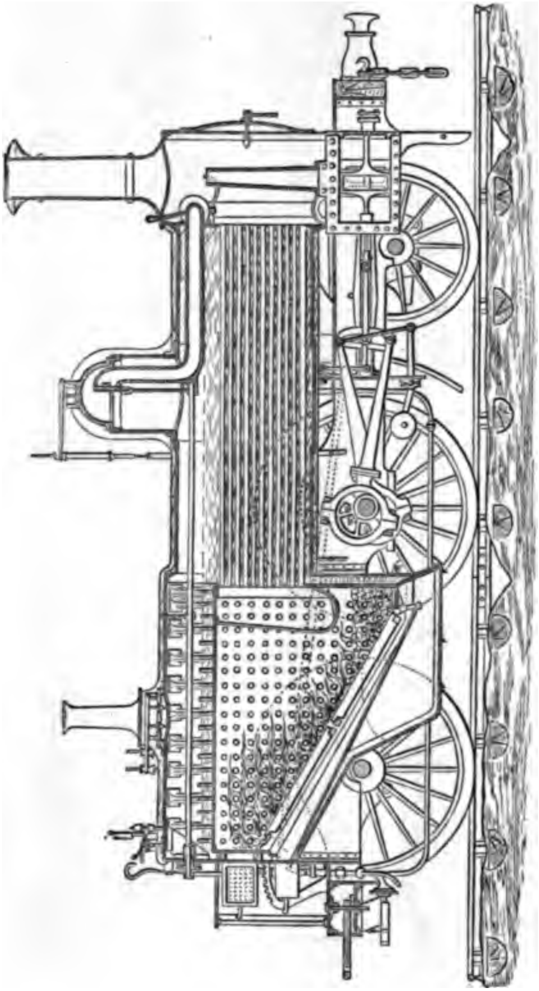


Fig. 141.—Cudworth's Coal-burning Locomotive. South Eastern Railway.

WEBB'S COMPOUND LOCOMOTIVE.

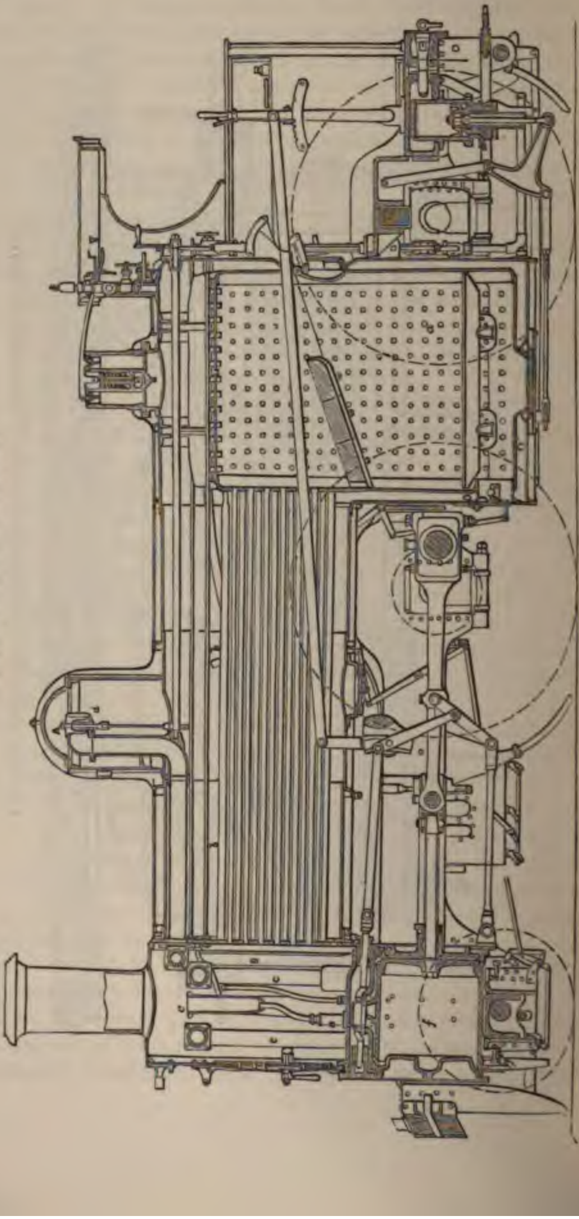
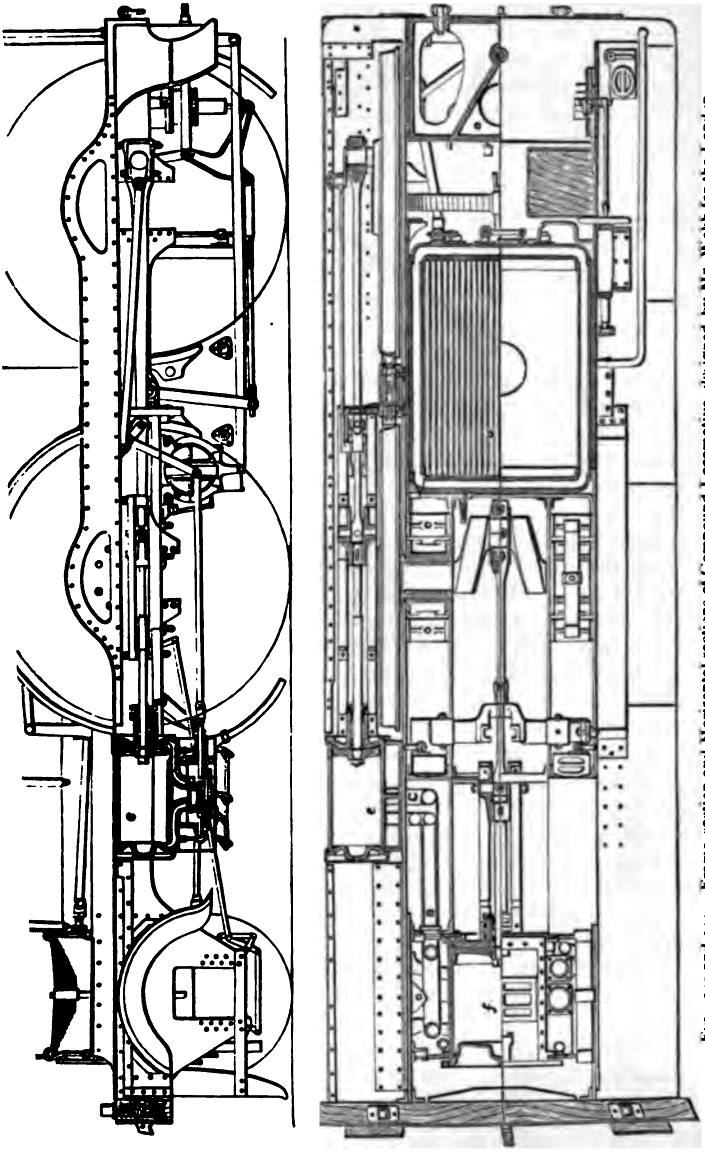


Fig. 142.—Vertical Longitudinal section of Compound Locomotive, designed by Mr. Webb for the London and North Western Railway, 1883.



Figs. 143 and 144. Frame section and Horizontal sections of Compound Locomotive, designed by Mr. Webb for the London and North Western Railway, 1883.

system; whereas there is no reason to doubt that the same steam, used with the same measure of expansion in simple engines, would have been equally economical and effective. In locomotives any avoidable complication is an evil, and, as has been found in torpedo-boats, the boilers of compound engines are more liable to prime than the boilers of non-compound engines.

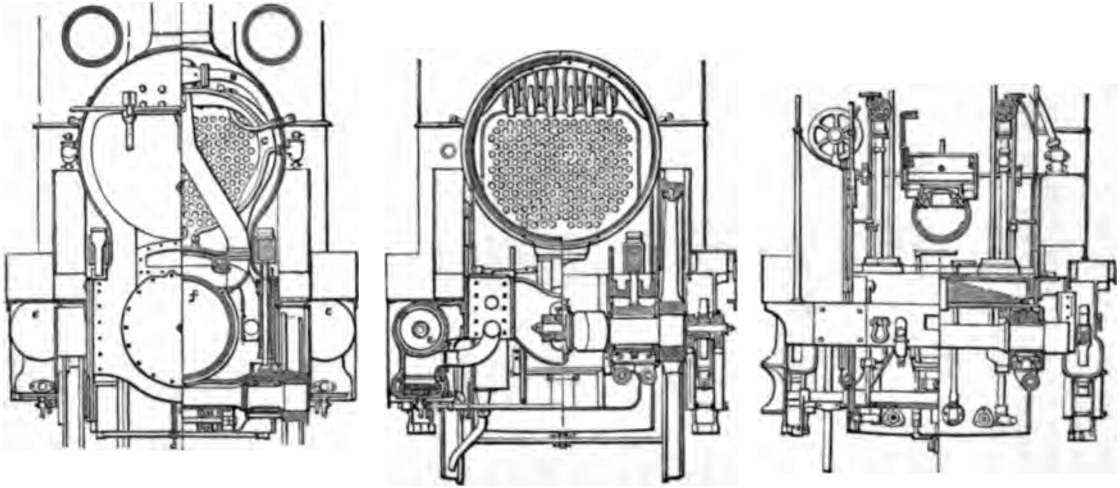
Q. Will you give an example of a compound locomotive?

A. I will select for this purpose the compound locomotive designed by Mr. Webb for the London and North Western Railway, and which is represented in figs. 142 to 147. *a*, is the fire-box; *b b*, the tubes; *c*, the smoke-box; *d*, the regulator; *e e*, the high-pressure cylinders; and *f*, the low-pressure cylinder. It will be seen that there is a high-pressure cylinder on each side, in the usual position of outside cylinders, and a low-pressure cylinder in the centre, which receives its steam from the high-pressure cylinders, and which dismisses the steam finally into the chimney. The steam-dome of the boiler is shown at A, and the steam is conducted thence through two 3-inch copper pipes, B, to the two high-pressure cylinders. The steam educted by the high-pressure cylinders is led through two 4-inch copper pipes, C, into the low pressure cylinder, whence it finally escapes into the chimney. There is a safety-valve, D, on the cover of the low-pressure slide, loaded to 75 lbs. per square inch. The valve gear is that known as Joy's, the chief peculiarity of which is that it derives the motion for working the valves from the connecting-rods instead of from eccentrics—an arrangement similar to that employed by Melling, Hawthorn, and others more than 40 years ago. The axle driven by the high-pressure engines, it will be observed, has no direct connection with that driven by the low-pressure cylinder, and it is alleged in favour of this arrangement that it gives a power of adapting itself to curves, such as would not otherwise be possessed. That power, however, would be greater if in an ordinary locomotive the two driving wheels on one side were to be driven by one engine, and the other two driving wheels by the other engine.

Q. Do you expect that locomotives of this type will come into general use?

A. I do not. They are too complicated, and attain no result that may not be equally attained by simpler means. Ordinary engines made with a good long stroke, steam-jacketed cylinders, and with steam of a high pressure worked expansively would be equally economical in fuel and much simpler in construction.

WEBB'S COMPOUND LOCOMOTIVE.



Half front view of smoke-box.
Half section through smoke-box.

Half cross-section through cylinder.
Half cross-section through driving wheel.

Half front view of fire-box.
Half cross-section through trailing wheels.

Figs. 145, 146, and 147.—End Views and Cross-sections of Compound Locomotive, designed by Mr. Webb for the London and North Western Railway, 1883.

Q. What are the sizes of the cylinders of the latest engines made upon this plan?

A. The two high-pressure cylinders are each of 13 inches diameter, and the low-pressure engine is 26 inches diameter. The stroke of each is 24 inches. The diameter of the blast-pipe is $4\frac{5}{8}$ inches.

Q. And what of the boiler?

A. The length of the barrel is 9 feet 10 inches, and its mean diameter 4 feet $1\frac{3}{16}$ inches. The length of grate is 4 feet $10\frac{1}{2}$ inches, and its breath 3 feet $5\frac{1}{2}$ inches. There are 198 tubes, 10 feet 1 inch long and $1\frac{7}{8}$ths external diameter. Heating surface of tubes, 980 square feet; heating surface of fire-box, 103·5 square feet; total heating surface, 1,083·5 square feet; ratio of heating surface to grate area, 63·35 to 1. Weight empty, 34·75 tons.

Q. You have stated that in Ramsbottom's locomotive of 1865 the heating surface was 1,000 square feet and the weight 27 tons, whereas it appears that in Webb's compound the heating surface is 1,083 square feet, and the weight $34\frac{3}{4}$ tons. Will the cost vary nearly as the weight?

A. It will. The effective power of the compound locomotive with the same pressure of steam will be about the same as that of the simple locomotive, while its weight, cost, and complication will be greater. Inside cylinders made as large as will go within the frames, jacketed, and with a good long stroke, the steam being of a very high pressure and worked very expansively, is the most promising combination that can be at present discerned.

CHAPTER IX.

ON VARIOUS FORMS AND APPLICATIONS OF THE STEAM ENGINE.

PORTABLE AGRICULTURAL ENGINES.

Q. Having now described the more important forms of the steam igine, as employed in pumping water, in driving mills, and in complishing locomotion, will you proceed to describe some of most approved forms as applied to miscellaneous uses in the ts?

A. The purposes for which the steam engine is employed in e arts are of infinite variety. It has long been employed in mping and in giving motion to the machinery of cotton, flax, oollen, corn, and other mills. More recently, however, it has und a new application in aiding the operations of agriculture, nd a new class of engines has been called into existence to meet is demand. These engines are, as a general rule, simple in con-ruction, very compact, and so contrived as not to be liable to erangement, even in the hands of unskilful persons. These agri-ltural engines are divisible into three main classes—portable gines set on wheels somewhat in the manner of a locomotive, d which may be drawn by horses from place to place; semi-rtable, resembling the others but not set on wheels; and fixed gines, which are set up on a brick, stone, or wooden foundation, ere there is constant work to do. Many of the fixed engines good examples of the kind of engine suitable for driving manu-tories. A description of this class of engine having been already en, it will not be necessary to dwell longer on that subject.

Q. Will you describe the main features of the portable engine?

A. The portable agricultural engines of the principal makers that species of engine are, in all their main features, similar to one another. They all consist of a boiler with an internal fire-box, and horizontal tubes resembling very much a locomotive boiler, and on the top of the boiler a cylinder is fixed with the connecting-rod attached to the end of the piston-rod, as in a locomotive, and the connecting-rod turns the crank of a shaft extending across the top of the boiler, on which shaft-pulleys are placed to communicate the motion of the engine by means of belts to any mechanism which requires to be driven. In the subordinate features of each engine, however, there are differences which render any one engine more or less eligible than the rest. The increasing power of agricultural engines has induced Messrs. Ransomes and Co. to employ for the larger powers a form of combined engine, consisting of two engines placed side by side, with the cranks at right angles, as in locomotives. An example of this form of engine is given in fig. 148.

Q. What are the distinctive features of these engines?

A. The engines are mounted upon the top of the boiler, and are in all their parts of the simplest character. The various details have been matured by the fruits of a long experience under all kinds of management in every quarter of the world. The fly-wheels are accurately balanced; the cylinders are tied to the crank-shaft brackets by connecting tie-bolts, which take the strain off the bolts connecting the brackets with the boiler. The fore-axle is connected to the boiler by means of a hemispherical locking-gear, which allows of the boiler always resting upon three points.

Q. How upon three points?

A. The two large wheels where they touch the ground constitute two of the points, and the centre of the swivelling axle on which the boiler rests is the third point. Any object which is supported on three points rests firmly upon any surface however undulating. But if it has more than three points to rest upon it may rock.

Q. Is this law of universal application?

A. It is. A piece of iron in the planing machine if wanted to be true when rested on any other surface, should rest upon three points on the table of the machine, and the catches which hold it on the table should be relaxed for the last cut, which should be a very light one. Whitworth's face-plates are hung or supported upon three points, and it would have been impossible to get a perfectly true plane upon any other conditions. Ransome's arrangement is therefore correct.

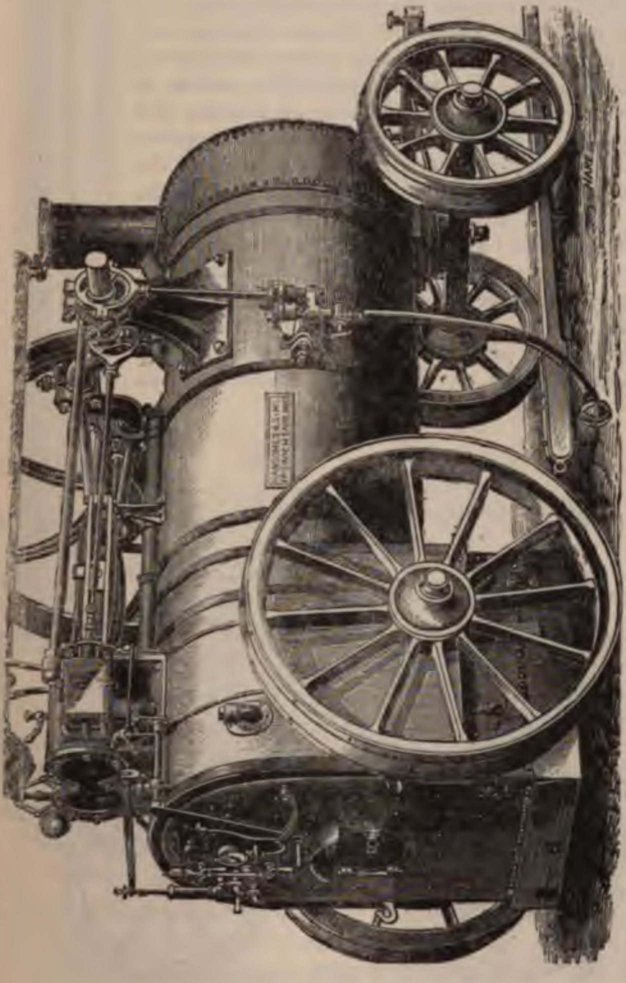


Fig. 148.—Ransomes and Sims' Combined Portable Engine of 20 horses-power.

Q. Will you describe the portable agricultural engines of Messrs. Clayton and Shuttleworth?

A. These engines are represented by figs. 149 and 150. The efforts of Messrs. Clayton and Shuttleworth to simplify and perfect this species of engine have had a very powerful operation in inducing its extended adoption by farmers and contractors; and great numbers of portable engines of similar configuration are now constructed by the manufacturers of agricultural engines. Messrs. Clayton and Shuttleworth state, that the clumsy and dangerous boilers put into the hands of farmers up to 1845 at that time attracted their attention, from the number of accidents arising in consequence of such defects; and the machinery was altogether so precarious that it was unsafe for any but an experienced man to be trusted with its

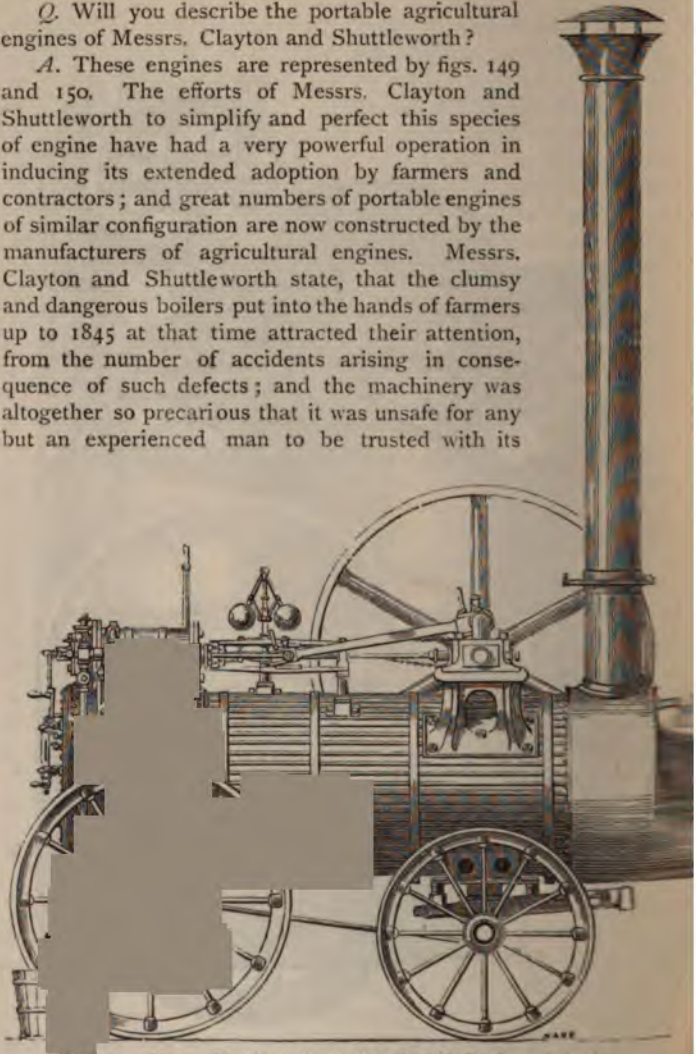


Fig. 149.—Clayton, Shuttleworth, and Co.'s Portable Engine. Elevation.

custody, thus rendering it as much an incumbrance as a benefit to the farmer. In 1849 they entered into competition with other makers at the Norwich show of the Royal Agricultural Society, and obtained the second prize of 25*l*., since which time the number of prizes they have taken, and the quantity of engines they have sold and delivered, attest the high opinion in which their engines are held both by the judges of the Royal Agricultural Society and the general public.

The following tabular statement of the duty done at various epochs of the early history of these engines shows that there was a gradual crease in their efficiency, owing to improvements from time to ne introduced. Since 1855 the consumption has been still fur- er reduced. Some portable engines have worked with 2½ lbs. f coal per actual horse-power, and even considerably less than at.

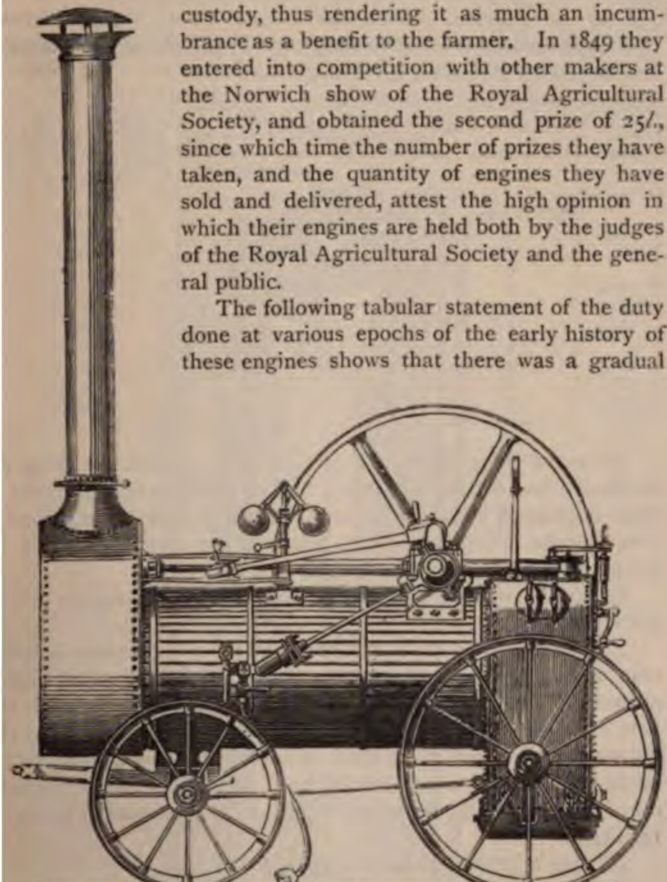


Fig. 150.—Clayton and Shuttleworth's Portable Engine. Elevation.

Duty of Clayton, Shuttleworth, and Co.'s Engines, at the Experiments tried before the Judges of the Royal Agricultural Society of England, up to 1855.

Years	Horses-power	Time getting up steam to 45 lbs. per inch	Coal used in getting up steam to 45 lbs. per inch	Coal burnt per Horse-power per Hour while doing the work of one actual Horse-power
	H.P. Engine.	Minutes	lbs.	lbs.
1849	5	44	32·25	11·8
	7	45	37·75	10·78
	9	37	41·25	11·66
1850	7	43	36·5	7·77
1851	6	32	35·4	8·63
1852	6	32½	22·75	6·0
	4	41	29·5	8·40
1853	4	47	17·75	4·32
1854	6	39		5·19
1855	8	34		4·05

In one of these figures the cylinder is represented as being set at the fire-box end of the boiler, but in more recent examples of their engines it is set in the smoke-box at the foot of the chimney. The cylinder is surrounded by a steam-jacket, which is kept at the temperature of 400° by the escaping smoke.

Q. For what purposes about a farm are steam engines principally used?

A. For thrashing corn, pumping water, sawing timber, bruising oats or beans, chopping up hay, and a number of other similar purposes. Sometimes the waste steam is made use of to cook the food of cattle, and to heat drying lofts. Engines of some of the classes described are much used by contractors for pumping water, mixing mortar, moulding bricks, hoisting stones, and performing other laborious tasks, for which a considerable amount of power is required.

Q. Has it been used for ploughing?

A. Yes; one of the most important applications of the portable engine in agriculture is to the work of steam ploughing, for which each principal manufacturer has some special arrangement. That known as Savory's system is represented in fig. 151. By this plan an engine suitable for winding a rope is placed on each side of a field, and the engine on the one side winds up a rope passing across the field which the other engine unwinds. The plough is attached to this rope, and it is drawn to one side and to the other by each engine alternately, each advancing a short distance along the field for every cut that is made. The modern practice, however, is to have two ropes and two ploughs simultaneously crossing the field as well as two engines, whereby the whole time of the engines is utilised.

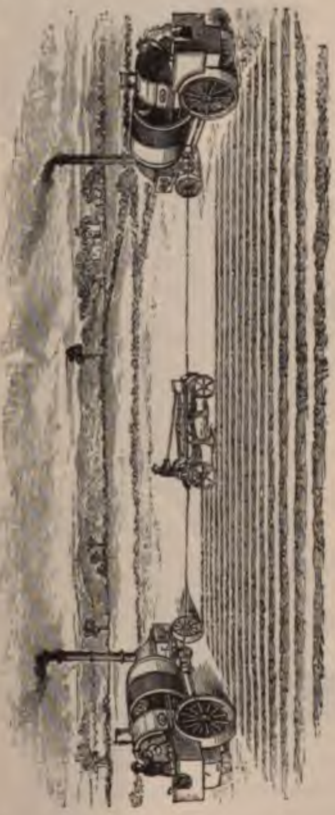


Fig. 151.—Savory's system of Steam Ploughing. By R. Garrett and Son

Q. Will not the portable engine require to be modified in some of its details to fit it for ploughing?

A. Yes; but its essential features remain unchanged. Fig. 152 is a representation of Fowler's ploughing engine, in which it will

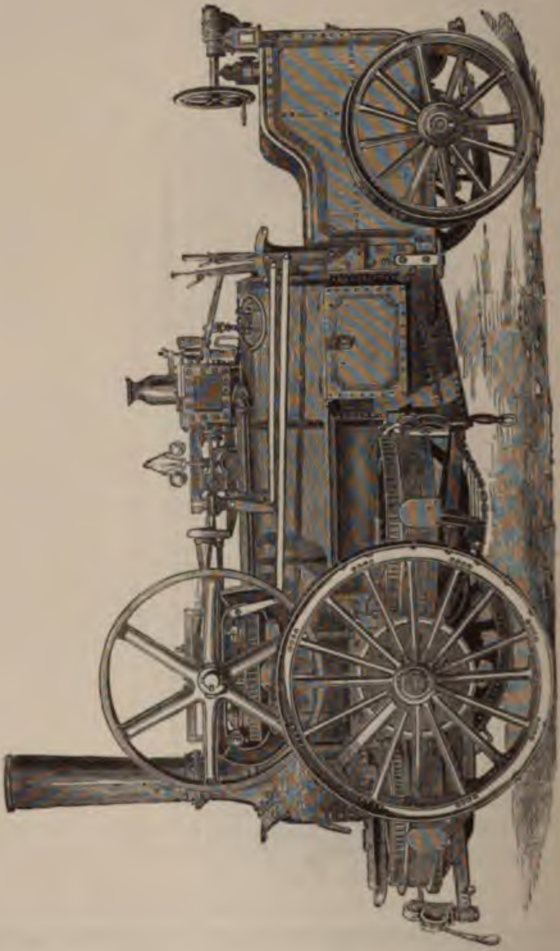


Fig. 152.—Fowler's Ploughing Engine.

be seen there are two drums rotating on vertical axes beneath the boiler, on one of which the engine is winding up the wire rope, drawing the frame of ploughshares, while the engine at the opposite side of the field is at the same time winding up the other rope, and consequently unwinding it from the drum here represented. In point of fact an endless rope would answer as well as two ropes, and an endless rope may be made to work two sets of ploughs by being passed over a movable pulley at the opposite side of the field, without the necessity of using two engines. The single engine, however, would require to have the same power as the two it superseded to do the same work in the same time, and there would be the trouble and delay incidental to the moving of the pulley and its anchors, while the weight of an engine constitutes anchor enough. All things considered, therefore, the plan of having two engines and two ropes passing across the field appears to be the best yet introduced.

Q. Has any species of steam-digger been projected?

A. Yes; one expedient which has been proposed is to have revolving ploughshares set on an axle, driven by a locomotive engine, which is slowly advanced by the ploughshares biting the ground, in the manner a steam vessel is propelled by paddle-wheels. This last expedient, termed Usher's steam-plough, is represented in fig. 153, but it cannot be said to have come into use.

Q. Will you describe the structure and operation of Usher's steam-plough?

A. The machine substantially consists of a locomotive engine with the fore wheels made to swivel, so as to guide the machine, while the hind wheels consist of a great drum stretching across beneath the engine, to prevent the weight from sinking the machine too deep in the soft ground. At the end of the engine an axle runs across from side to side, carrying any required number of sets of revolving ploughshares, and this axle can be raised or depressed by appropriate mechanism, so as to give the ploughshares any amount of dip which may be found expedient. The axle carrying the ploughshares has its speed reduced, and its force of rotation increased, by the interposition of gearing between it and the engine.

Q. Describe the apparatus in greater detail.

A. Referring to the figure, *a′ a′* is the wheel carrying the three ploughshares *e e′ e″*; each ploughshare is preceded by a coulter or cutter, and a succession of similar wheels and ploughshares is set upon the axle, so that the machine ploughs its own breadth at once. The wheels of the fore carriage are lettered *b b*, and *f* is the great drum stretching across the engine to support the weight. The drum is fixed on the axle *g*. The cylinder of the engine is shown at *n*, and *o* is the connecting rod turning the crank. On the crank-shaft is placed a pinion *p*, working into the large spur wheel *g'*, which turns on the axle *k*; and a pinion affixed to *g'* gives motion to a wheel fixed to the drum *f*. At the same time *g'* gears into a smaller wheel on the axis *u*, and so puts the rotating ploughshares into revolution. The axle *u* is supported by the framework *i i*, which by turning round the cross-handle attached to a small pinion gearing with the sector *l*, may be moved like a vibrating beam on the centre *k*, and the bite of the revolving ploughshares may therefore be increased or diminished by turning in the appropriate direction the cross-handle at *l*. It will be

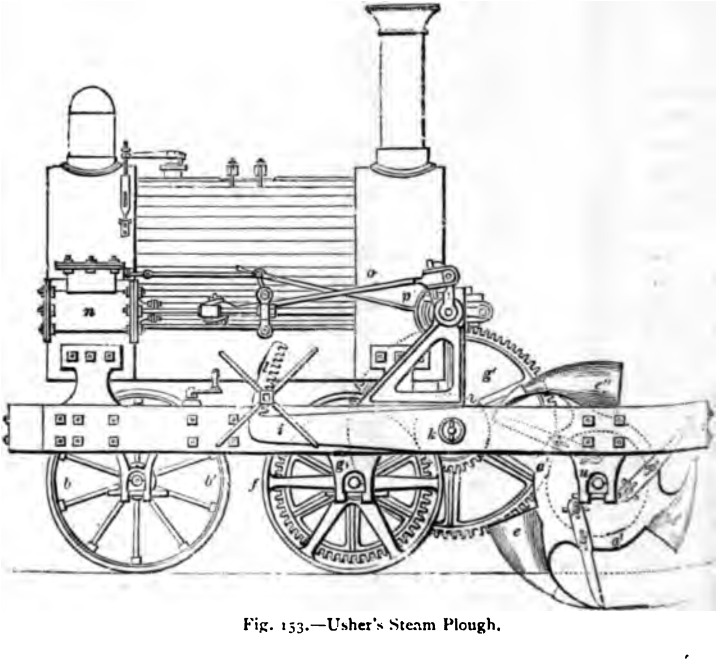


Fig. 153.—Usher's Steam Plough.

obvious that as the frame *i i* vibrates on the same centre on which the wheel *g'* revolves, that the elevation or depression of the ploughshares does not affect the gear of the wheels.

Q. Have steam engines been made to travel on common roads like locomotives upon railways?

A. Yes; steam traction engines have been used for some purposes. But the extension of tramways on common roads appears likely to limit the employment of such engines, as the traction on tramways is so much less.

Q. Was it not at one time expected that steam coaches on common roads would take the place of the horse coaches at that time running?

A. Yes, that expectation was entertained. But it was in ignorance or forgetfulness of the fact that a steam coach of any kind, to achieve any considerable speed, must necessarily be heavy, and that the whole power of such a machine would be expended in propelling its own weight with the necessary load of fuel and water.

Q. What is the relative resistance of wheeled vehicles upon good roads and upon railways or tramways, supposing both to be level?

A. Upon good roads it is about $\frac{1}{30}$th of the weight. Upon railways or tramways at low speeds it is $\frac{1}{300}$th of the weight.

Q. Then the deduction from the carrying power to be made in the case of a railway or tramway for the weight of the engine itself is very small relatively with the deduction which has to be made in the case of steam traction upon common roads?

A. Precisely so, and it was soon seen that to accomplish any considerable amelioration railways were necessary, and that where they were made steam upon the common road had no possible chance of success. Nor is it merely in regard to the high resistance that the objection to steam on common roads exists. It would be impossible, in the midst of a miscellaneous traffic, to run steam coaches at a high rate of speed; and unless a high rate of speed were attained no adequate inducement to the supersession of horses by steam power could be presented, seeing that the weight of the engine and the cost of its traction were so great. Traction engines have this advantage over horses for drawing heavy weights—that they are under better control, whereas it is difficult to get a large number of horses to pull together. The structure and configuration of traction engines are very similar to those of ploughing engines.

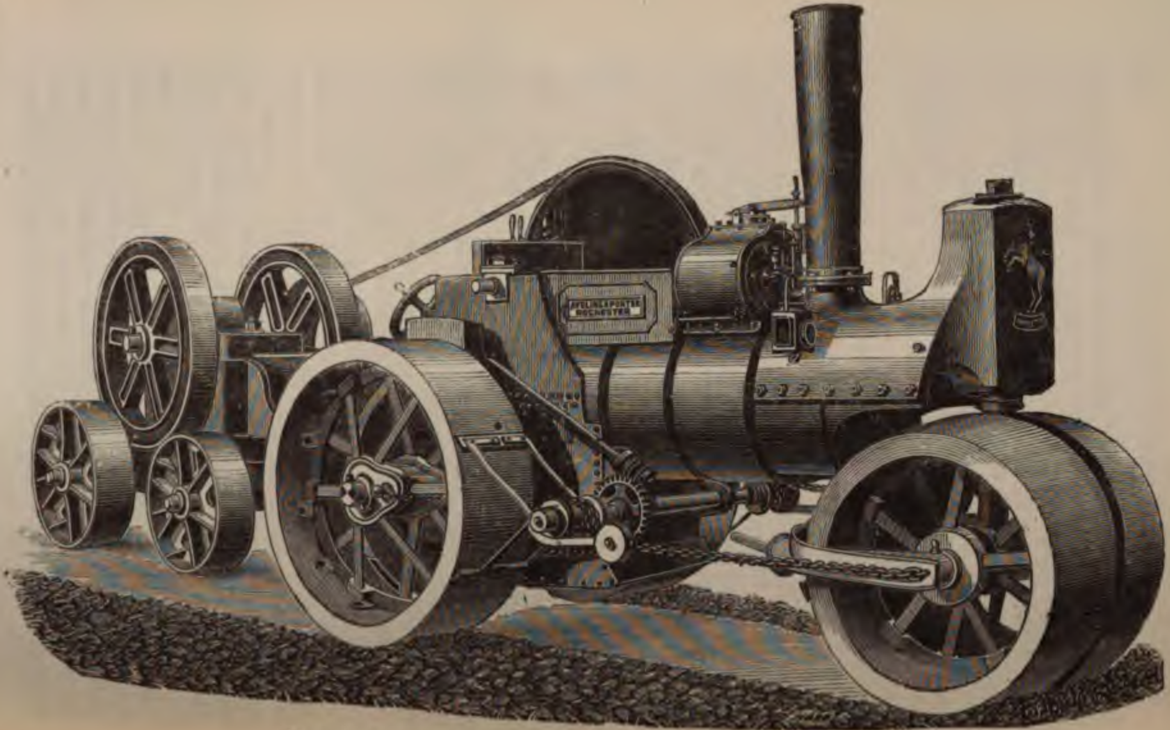


Fig. 154.—Aveling and Porter's Steam Road-Roller with Stone-Breaker Attached.

Q. May not the same be said of steam road-rollers for consolidating the broken stones by which roads are made or mended?

A. The steam road-roller is a modification of the traction engine. Aveling and Porter's steam road-roller is represented in fig. 154 with a stone-breaker attached. The engine is carried upon four wheels of equal width, the two hind wheels acting as driving and the two fore as steering wheels. When a road is newly covered with broken stones, it is consolidated by driving the roller backward and forward over the surface, which is at the same time wetted and sprinkled with gravel to facilitate the consolidation. Very heavy rollers like those used in France have been found to crush the pipes laid beneath the road.

Q. Will you describe Thomson's road-roller?

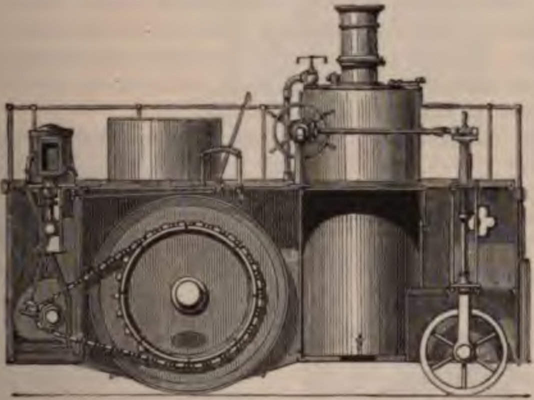


Fig. 155.—Thomson's Steam Road-Roller.

A. This engine is represented in fig. 155. There are two cylinders working downward to a cross-shaft, which carries two pitched chain pinions that give motion through the medium of the chains to the roller, which constitutes one great driving wheel extending from side to side of the carriage. The steering is accomplished by the aid of the leading wheels, each of which is carried in a forked vertical axis capable of being swivelled by a worm wheel at its upper end. The whole machinery is carried by a wrought-iron framing 19 feet 8 inches long, 8 feet wide, and 6½ feet deep, and standing 8 feet above the roadway. The total weight of the machine is 25½ tons, of which 21½ tons are carried by the roller and the rest by the leading wheels. The roller is 6 feet long and 7½ feet diameter, and is constructed of wrought-iron plates, riveted together, the plate being ½ inch thick, with internal stiffening stays; and wearing plates are applied to its exterior, which may be renewed when worn out. The cylinders are each of 11 inches diameter and 18 inches stroke, and five revolutions of the engines produce one of the roller. The boiler is vertical, 4 feet 2 inches diameter and 10 feet 3 inches high, with 64 Field tubes, 2¼ external diameter. The engine is fitted with the link motion, to render reversing easy. The road, after being picked and covered with broken stone mixed with a little sand or gravel, is well watered, and the roller is run backward and forward over it a few times, when it is found to be perfectly consolidated, and fit for immediate traffic. The machine does not require to be turned round at the end of its beat, but only backed, as it will run indifferently in either direction; and, like a great mangle, it smooths down the road much more effectually than traffic could do, and without any injurious attrition of the stones upon one another.

Q. Is the centrifugal pump now much used for agricultural purposes?

A. It is.

Q. What is the best form of that pump?

A. The best form of centrifugal pump is that of Appold, with curved vanes, as represented in fig. 156. In 1851, pumps by Appold, with straight vanes, with inclined vanes, and with curved vanes, were carefully tested, and it was found that the work done relatively to the power expended amounted with the pump with straight vanes to 24 per cent., with the pump with inclined vanes to 43 per cent., and with the pump with curved vanes — such as are shown in fig. 156—to 68 per cent. This pump has been much used in raising water for irrigation, for draining land and foundations, for pumping out docks, and for various other

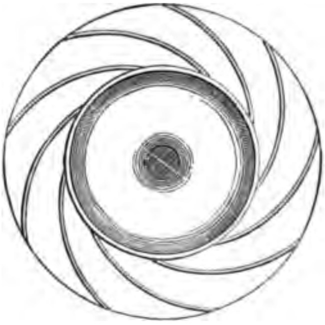


Fig. 156.—Appold's Centrifugal Pump. By Easton, Amos, and Son.

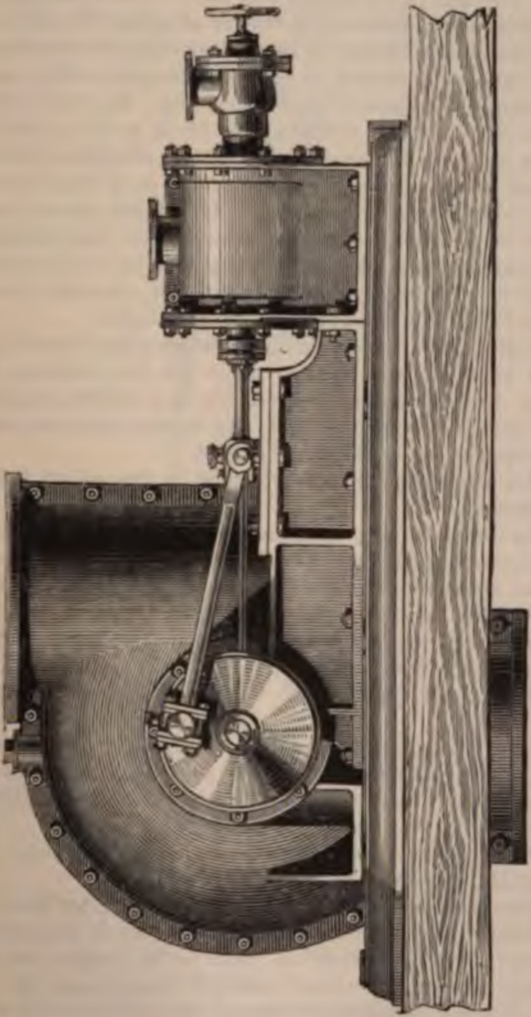


Fig. 157.—Gwynne's Direct-acting Centrifugal Pump.

purposes for which low lifts are required. But for some of these purposes the chain pump, formed with square boards moving slowly in a wooden trunk, appears to be fully as effective. The centrifugal pump is sometimes driven by toothed wheels, and sometimes by serrated surfaces of contact, or the circumferential ridges and furrows known by the name of frictional gearing. But toothed wheels require to work so very fast when the lift is at all considerable, that they are soon cut away, and it appears advisable when gearing is used in such cases to make it spiral, or in steps, and with the teeth bottoming and very broad. If frictional gearing is used, it should be of much greater breadth and power than the authors of that scheme deem necessary, seeing that in certain cases the wheels which have been deemed by them of adequate size have been found quite insufficient to transmit the strain.

Q. May not the pump be driven direct by a high-speed engine?

A. It may, and this appears to be the best solution of the question. Fig. 157 is the representation of a centrifugal pump by Messrs. Gwynne, driven in this way, and in most cases intermediate gear of any kind has now been discarded.

Q. Has the engine here represented its momentum balanced by counterweights?

A. No; and this is a disadvantage. High-speed engines will move uneasily unless so balanced. The crank-pin, moreover, should not be overhung. The cylinder also would be better if set lower, as where it joins the framing opposite the cylinder-cover it will be liable to spring. These faults, however, Messrs. Gwynne have corrected in subsequent engines.

Q. What is the velocity with which a centrifugal pump must work?

A. That depends on the height to which it has to lift the water. In every case the periphery of the pump must move with a greater velocity than water would acquire in falling from that head.

Q. What are the cases for which the centrifugal pump is the most suitable instrument?

A. The cases are where large quantities of water have to be lifted against a low head, especially if the water is impure, as the centrifugal pump has no valves liable to be gagged, but sends everything through. In steam vessels it is much used for maintaining a current of sea-water through the tubes of the surface condenser whereby the necessary refrigeration is maintained.

Q. Will you describe the structure and action of the steam-hammer?

A The steam-hammer was originally invented by Watt, but was allowed to remain in abeyance for half a century, until re-invented

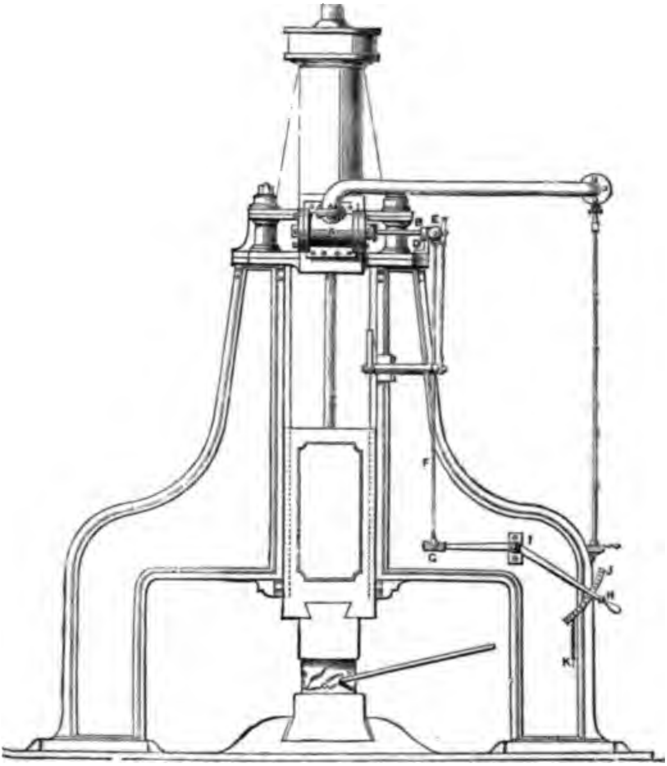


Fig. 158.—Nasmyth's Steam-Hammer. Elevation.

nd carried into practical operation, by Mr. James Nasmyth. A epresentation of this hammer is given in fig. 158, where A is the cylinrical slide-valve, worked by the spindle B, supported by a bracket D, olted to the hammer framing; E is a lever jointed to a rod F, assing down to the level of the workman's hand, and jointed at G to he cranked lever H, which turns on a slud I, bolted to the framing.

To work the hammer, this lever is merely worked up and down. The cylinder, which stands on top of the framing, has a piston-rod passing through the bottom and engaging a great block of metal, which constitutes the hammer. When the steam is admitted beneath the piston the hammer is lifted, and when admitted above the piston the hammer is forced down, both by the pressure of the steam and by its own weight. The force of the blow will be determined by the amount of opening given to the slide-valve by the handle H, and this may be determined by putting the pin K into one of the holes of the quadrant J, and by bringing the handle up against the pin which has been inserted in the selected hole. Steam-hammers of various sizes, suited to the purposes for which they are employed, are now in extensive use in the workships of all civilised countries.

Q. Can you give any example of the power necessary for grinding corn?

A. An engine exerting 23½ horses-power by the indicator works two pairs of flour-stones of 4 feet 8 inches diameter, two pairs of stones grinding oatmeal of 4 feet 8 inches diameter, one dressing-machine, one pair of fanners, one dust-screen, and one sifting-machine. One of the four stones makes 85 and the other 90 revolutions in the minute. One of the oatmeal-stones makes 120 and the other 140 revolutions in the minute. To take another case:—An engine exerting 26⅓ indicator horse-power works two pairs of flour-stones, one dressing-machine, two pairs of stones grinding oatmeal, and one pair of shelling-stones. The flour-stones, one pair of the oatmeal-stones, and shelling-stones are 4 feet 8 inches diameter. The diameter of the other pair of oatmeal-stones is 3 feet 8 inches. The length of the cylinder of the dressing-machine is 7 feet 6 inches. The flour-stones make 87 revolutions in the minute, and the larger oatmeal-stone 111 revolutions, but the smaller oatmeal-stone and the shelling-stone revolve faster than this. At the time the indicator diagram was taken, each pair of flour-stones was grinding at the rate of 5 bushels an hour; each pair of oatmeal-stones about 24 bushels an hour; and the shelling-stones were shelling at the rate of about 54 bushels an hour. The fanners and screen were also in operation.

Q. Have you any other cases to enumerate?

A. I may mention one, in which the power of the same engine was increased by giving it a larger supply of steam. The engine when working with 8·65 horses-power, gives motion to one pair of oatmeal-stones of 4 feet 6 inches diameter, and one pair of flour-stones 4 feet 8 inches diameter. The oatmeal-stone makes 100 revolutions in the minute, and the flour-stone 89. The oatmeal stones grind about 36 bushels in the hour, and the flour-stones 5 bushels in the hour. The engine when working to 12 horses-power drives one pair of flour-stones, 4 feet 8 inches diameter, at 89 revolutions per minute, and one pair of stones of the same diameter at 105 revolutions, grinding beans for cattle. The flour-mill stones with this proportion of power, being more largely fed, ground 6 bushels per hour, and the other stones also ground 6 bushels per hour. When the power was increased to 18 horses, and the engine was burdened in addition with a dressing-machine having a cylinder of 19 inches diameter, the speed of the flour-stone fell to 85, and of the beans-stone to 100 revolutions per minute, and the yield was also reduced. The dressing-machine dressed 24 bushels per hour.

Q. What is the power necessary to work a sugar mill such as is used to press the juice from canes in the West Indies?

A. Twenty horses-power will work a sugar mill having rollers about 5 feet long and 28 inches diameter; the rollers making 2¼ turns in a minute. If the rollers be 26 inches diameter and 4½ feet long, 18 horses-power will suffice to work them at the same speed, and 16 horses-power if the length be reduced to 3 feet 8 inches. 12 horses-power will be required to work a sugar mill with rollers 24 inches diameter and 4 feet 2 inches long; and 10 horses-power will suffice if the rollers be 3 feet 10 inches long and 23 inches diameter. The speed of the surface of sugar mill rollers should not be greater than 16 feet per minute, to allow time for the canes to part with their juice. In the old mills the speed was invariably too great. The quantity of juice expressed will not be increased by increasing the speed of the rollers, but more of the juice will pass away in the begass or woody refuse of the cane.

Q. What is the amount of power necessary to drive cotton mills?

A. An indicator or actual horse-power will drive 305 hand-mule spindles, with proportion of preparing machinery for the same, or 230 self-acting mule spindles with preparation, or 104 throstle-spindles with preparation, or 10½ power looms with common sizing. The throstles referred to are the common throstles spinning 34's twist for power-loom weaving, and the spindles make

4,000 turns per minute. The self-acting mules are Roberts', about one half spinning 36's weft, and spindles revolving 4,800 turns per minute; and the other half spinning 36's twist, with the spindles revolving 5,200 times per minute. Half the hand-mules were spinning 36's weft, at 4,700 revolutions, and the other half 36's twist at 5,000 revolutions per minute. The average breadth of the looms was 37 inches, weaving 37-inch cloth, making 123 picks per minute,—all common calicoes about 60 reed, Stockport count, and 68 picks to the inch. To take another example, in the case of a mill for twisting cotton yarn into thread:—In this mill there are 27 frames with 96 common throstle-spindles in each, making in all 2,592 spindles. The spindles turn 2,200 times in a minute; the bobbins are 1⅞ inches diameter, and the part which holds the thread is 2 3/16 inches long. In addition to the twisting frames the steam engine works 4 turning lathes, 3 polishing lathes, 2 American machines for turning small bobbins, two circular saws, one of 22 and the other of 14 inches diameter, and 24 bobbin heads or machines for filling the bobbins with finished thread. The power required to drive the whole of this machinery is 28½ horses. When all the machinery except the spindles is thrown off, the power required is 21 horses, so that 2,592, the total number of spindles, divided by 21, the total power, is the number of twisting spindles worked by each actual horse-power. The number is 122·84.

Q. What work will be done by a given engine in sawing timber, pressing cotton, blowing furnaces, driving piles, and dredging earth out of rivers?

A. A high-pressure cylinder, 10 inches diameter, 4 feet stroke, making 35 revolutions with steam of 90 to 100 lbs. on the square inch, supplied by three cylindrical boilers 30 inches diameter and 20 feet long, works two vertical saws of 34 inches stroke, which are capable of cutting 30 feet of yellow pine, 18 inches deep, in the minute. A high-pressure cylinder, 14 inches diameter and 4 feet stroke, making 60 strokes per minute, with steam of 40 lbs. on the square inch, supplied by three cylindrical boilers without flues, 30 inches diameter and 26 feet long, with 32 square feet of grate surface, works four cotton presses, geared 6 to 1, with two screws in each of 7½ inches diameter and 1⅜ pitch, which presses will screw 1,000 bales of cotton in the twelve hours. Also one high-pressure cylinder of 10 inches diameter and 3 feet stroke, making 45 to 60 revolutions per minute, with steam of 45 to 50 lbs. per square inch, with two hydraulic presses having 12-inch rams of 4½ feet stroke, and force-pumps, 2 inches diameter and 6 inches stroke, presses 30 bales of cotton per hour. One condensing engine, with cylinder 56 inches diameter, 10 feet stroke, and making 15 strokes per minute with steam of 60 lbs. pressure per square inch, cut off at ¼th of the stroke, supplied by six boilers, each 5 feet diameter and 24 feet long, with a 22-inch double-return flue in each, and 198 square feet of fire-grate, works a blast cylinder of 126 inches diameter and 10 feet stroke, at 15 strokes per minute. The pressure of the blast is 4 to 5 lbs. per square inch ; the area of pipes, 2,300 square inches ; and the engine blows four furnaces of 14 feet diameter, each making 100 tons of pig-iron per week. Two high-pressure cylinders, each of 6 inches diameter and 18 inches stroke, making 60 to 80 strokes per minute, with steam of 60 lbs. per square inch, lift two rams, each weighing 1,000 lbs., five times in a minute, the leaders for the lift being 24 feet long. One high-pressure cylinder of 12 inches diameter and 5 feet stroke, making 20 strokes per minute, with steam of 60 to 70 lbs. pressure per square inch, lifts 6 buckets full of dredging per minute from a depth of 30 feet below the water, or lifts 10 buckets full of mud per minute from a depth of 18 feet below the water.

Q. What is the form of governor now employed in marine engines?

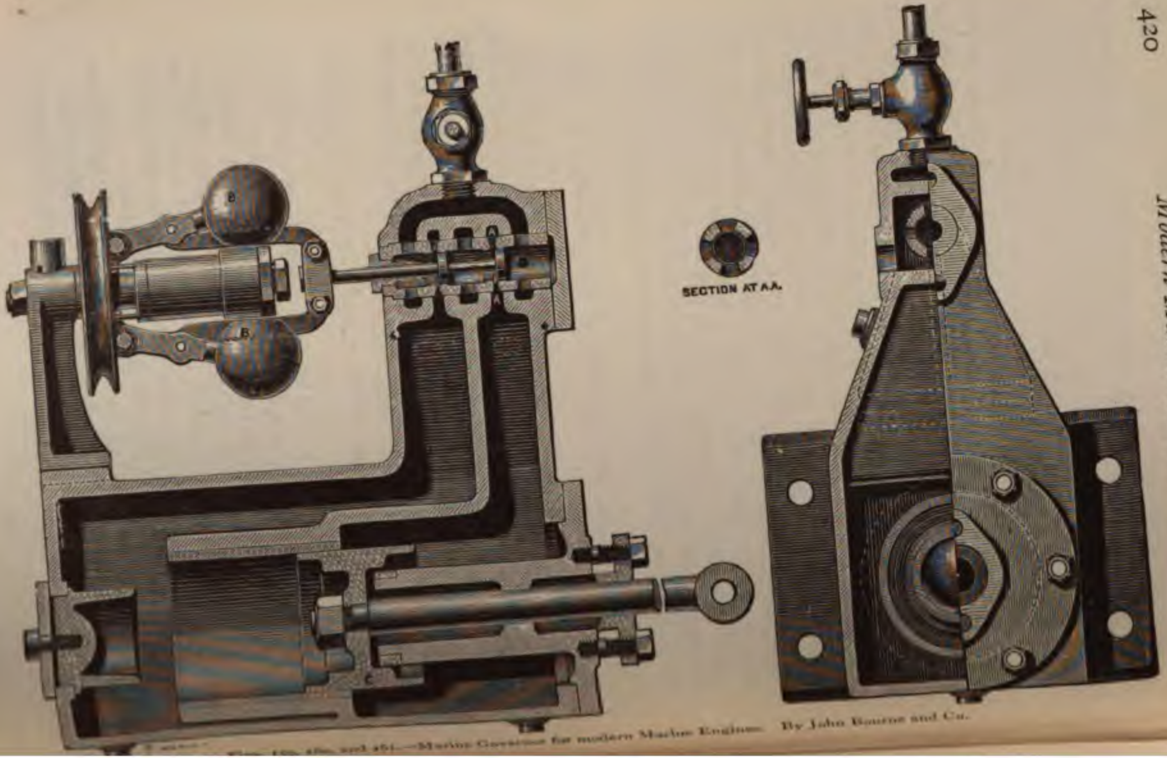
A. There are various kinds, but the most recent form is that shown in figs. 159, 160, and 161, where A A represents one of the steam-ports of a small cylinder ; B B, the governor balls of a small governor, the centrifugal expansion of which, put into revolution by a pulley, is resisted by a spiral spring ; C is the piston of the small cylinder. The piston is made of brass, and the cylinder also is lined with brass, as an antidote to corrosion.

Q. How does this arrangement regulate the speed of the main engines?

A. When the speed of the main engines is accelerated, in however slight a degree, the speed of the small governor is also accelerated and the divergence of the balls, which then overcome to a corresponding extent the tension of the spiral spring, acts upon the small piston-valve, and admits a little steam at A A. This at once moves the piston C, and its piston-rod acts upon throttle-valves in the steam and eduction pipes of the main engines.

Q. Might not the governor be made to act directly upon those valves, and thus obviate the necessity of having a small cylinder?

A. It might; but the governor in such event would be a very



[illegible] Figs. 459, 460, and 461.—Marine Governor for modern Marine Engines. By John Bourne and Co.

large affair, and its use would be attended with various difficulties. The original marine governor introduced by myself into a steamer in 1837 acted in this way. But the balls of that governor were 14 inches in diameter. In large engines the throttle-valves require a considerable expenditure of force to move them with the requisite rapidity, and if this resistance has to be overcome by the centrifugal force of the balls, they must necessarily be of large size. By the introduction, however, of the intermediate cylinder, the force necessary to overcome the resistance is contributed by it, and all

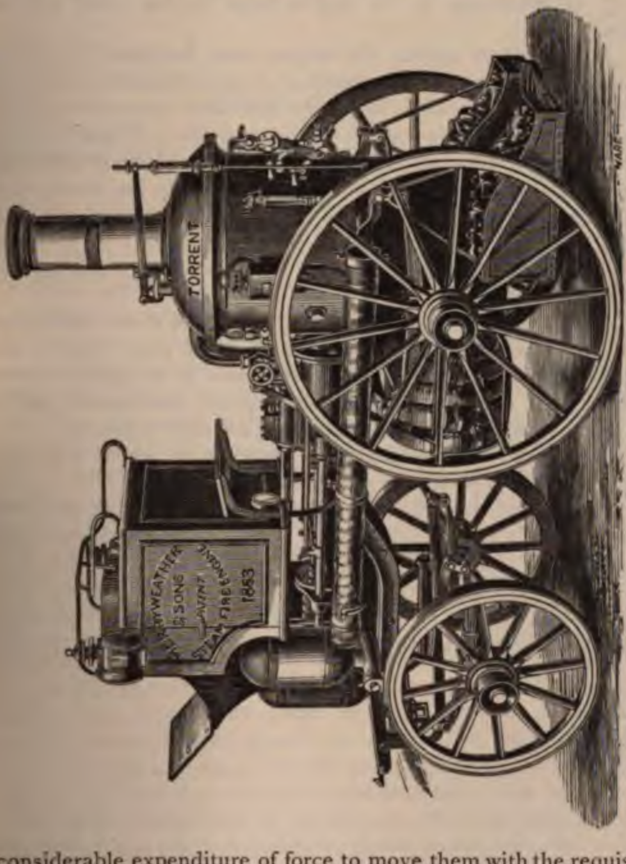

TORRENT
MERRYWEATHER & SONS PATENT STEAM FIRE ENGINE LONDON 1863

Fig. 162.—Steam Fire-Engine 'Torrent' constructed by Merryweather & Son.

that the governor has to do is to move the small piston-valve of the small engine. The small cylinder is filled with water before starting, and it is on the surface of this water that the steam acts, so that the expenditure of steam is quite insignificant.

Q. Whereabouts in the engine-room is this small cylinder placed?

A. It is bolted against the engine-room bulkhead, so that the driving cord comes near the bulkhead, and is not liable to accidental injury. The steam comes in through the small screw-valve, shown at the top of the apparatus, and a corresponding volume of water escapes by the eduction passage. The spontaneous condensation of the small quantity of steam admitted keeps up the supply of the small quantity of water required by the rapid action of the apparatus.

Q. Has this species of governor been found to give satisfactory results in practice?

A. It has been introduced into a number of steam vessels, and has been favourably reported upon in every case. But in such cases the recognition of judicious adaptation in the apparatus itself is a far safer credential than commendatory testimonials, such as all plans equally, whether good or bad, are able to present.

Q. Among the miscellaneous purposes to which the steam engine is now applied, one is to the extinction of fire?

A. Yes; an example of a steam fire-engine is given in fig. 162, consisting of a vertical boiler with Field tubes, a horizontal steam engine, and pump and other parts, as shown in the cut, which renders the structure so plain as to obviate the necessity of further description. These examples constitute only a small specimen of the multitudinous uses to which the steam engine is now applied.

CHAPTER X.

MANUFACTURE AND MANAGEMENT OF STEAM ENGINES.

CONSTRUCTION OF ENGINES.

Q. What are the qualities which should be possessed by the iron of which the cylinders of steam engines are made?

A. The liners of cylinders should be sound and hard; but it is expedient also to make the cylinders themselves tough, so as to approach as nearly as possible to the state of malleable iron. This may be done by mixing in the furnace as many different kinds of iron as possible; and it may be set down as a general rule in iron-founding, that the greater the number of the kinds of metal entering into the composition of any casting, the denser and tougher it will be. The constituent atoms of the different kinds of iron appear to be of different sizes, and the mixture of different kinds maintains the toughness, while it adds to the density and cohesive power. Hot-blast iron is generally believed to be weaker than cold-blast iron. The cohesive strength of unmixed iron is not in proportion to its specific gravity, and its elasticity and power to resist shocks appear to become greater as the specific gravity becomes less. Nos. 3 and 4 are the strongest irons. In most cases, iron re-melted in a cupola is not so strong as when re-melted in an air furnace, and when run into green sand it is not reckoned so strong as when run into dry sand or loam. The quality of the fuel, and even the state of the weather, exerts an influence on the quality of the iron. Smelting furnaces, on the cold-blast principle, have long been known to yield better iron in winter than in summer, probably from the existence of less moisture in the air; and it would probably be found to accomplish an improvement in the quality of the iron if the blast were made to pass through a vessel containing muriate of lime, by which the moisture of the air would be extracted. The expense of such a preparation would not be considerable, as, by subsequent evaporation, the salt might be used over and over again for the same purpose.

Q. Will you explain the process of casting cylinders?

A. The mould into which the metal is poured is built up of bricks and loam, the loam being clay and sand ground together in a mill, with the addition of a little horse-dung to give it a fibrous structure and prevent cracks. The loam-board, by which the circle of the cylinder is to be swept, is attached to an upright iron bar, at the distance of the radius of the cylinder, and a cylindrical shell of brick is built up, which is plastered on the inside with loam, and made quite smooth by traversing the perpendicular loam-board round it. A core is then formed in a similar manner, but so much smaller as to leave a space between the shell and the core equal to the thickness of the cylinder, and into this space the melted metal is poured. Whatever nozzles or projections are required upon the cylinder must be formed by means of wooden patterns, which are built into the shell, and subsequently withdrawn; but where a number of cylinders of the same kind are required, it is advisable to make these patterns of iron, which will not be liable to warp or twist while the loam is being dried. Before the iron is cast into the mould, the interior of the mould must be covered with finely powdered charcoal—or blackening, as it is technically termed; and the secret of making finely-skinned castings lies in using plenty of blackening. In loam and dry-sand castings the charcoal should be mixed with thick clay water, and applied until it is ⅛ of an inch thick, or more; the surface should be then very carefully smoothed or sleeked, and if the metal has been judiciously mixed, and the mould thoroughly dried, the casting is sure to be a fine one. Dry-sand and loam castings should be, as much as possible, made in boxes; the moulds may thereby be more rapidly and more effectually dried, and better castings will be got with a less expense.

Q. Will you explain the next operation which a cylinder undergoes?

A. The next stage is the boring; and in boring cylinders of 74 inches diameter, the boring-bar must move so as to make one revolution in about 4½ minutes, at which speed the cutters will move at the rate of about 5 feet per minute. In boring brass, the speed must be slower; the common rate at which the tool moves in boring brass air-pumps is about 3 feet per minute. If this speed be materially exceeded the tool will be spoiled, and the pump made taper. The speed proper for boring a cylinder will answer for boring the brass air-pump of the same engine. A brass air-pump of 36½ inches diameter requires the bar to make one turn in about three minutes, which is also the speed proper for a cylinder 60 inches in diameter. To bore a brass air-pump 36½ inches in diameter requires a week, an iron one requires 48 hours, and a copper one 24 hours. In turning a malleable iron shaft 12¾ inches in diameter, the shaft should make about five turns per minute, which is equivalent to a speed in the tool of about 16 feet per minute; but this speed may be exceeded if soap and water be plentifully run on the point of the tool. A boring-mill, of which the speed may be varied from 1 turn in 6 minutes to 25 turns in 1 minute will be suitable for all ordinary wants that can occur in practice.

Q. Are cylinders bored out from end to end?

A. No; modern engines are generally formed with a bush or liner, and in such case the external cylinder has only to be bored for a short distance at the mouth and bottom to enable the liner to be fitted. Liners are necessarily bored from end to end.

Q. Are there any precautions necessary to be observed in order that the boring may be truly effected?

A. In fixing a cylinder or a liner into the boring-mill, great care must be taken that it is not screwed down unequally; and, indeed, it will be impossible to bore a large cylinder in a horizontal mill without being oval, unless the cylinder be carefully gauged when standing on end, and be set up by screws when laid in the mill until it again assumes its original form. A large cylinder will inevitably become oval if laid upon its side; and if while under the tension due to its own weight it be bored round, it will become oval again when set upon end. If the bottom be cast in, the cylinder will be probably found to be round at one end and oval at the other, unless a vertical boring-mill be employed, or the precautions here suggested be adopted.

Q. How are the parts of a piston fitted together so as to be perfectly steam-tight?

A. The old practice was to depend chiefly upon grinding as the means of making the rings tight upon the piston or upon one another; but scraping is now chiefly relied on. Some makers, however, finish their steam-surfaces by grinding them with powdered Turkey stone and oil. A slight grinding, or polishing, with powdered Turkey stone and oil appears to be expedient in ordinary cases, and may be conveniently accomplished by setting the piston on a revolving table, and holding the ring stationary by a cross piece of wood while the table turns round. Pieces of wood may be interposed between the ring and the body of the piston, to keep the ring nearly in its right position; but these pieces of wood should be fitted so loosely as to give some side play, else the disposition would arise to wear the flange of the piston into a groove.

Q. What kind of tool is used for finishing surfaces by scraping?

A. A flat file, bent and sharpened at the end, makes an eligible scraper for the first stages; or a flat file, sharpened at the end, and used like a chisel for wood. A three-cornered file, sharpened at all the corners, is the best instrument for finishing the operation. The scraping tool should be of the best steel, and should be carefully sharpened at short intervals on a Turkey stone, so as to maintain a fine edge.

Q. Will you explain the method of fitting together the valve and cylinder faces?

A. Both faces must first be planed, then filed according to the indications of a thick metallic face-plate, and finally scraped very carefully until the face-plate bears equally all over the surface. In planing any surface, the catches which retain the surface on the planing-machine should be relaxed previously to the last cut, to obviate distortion from springing. To ascertain whether the face-plate bears equally, smear it over with a little red ochre and oil, and move the face-plate slightly, which will fix the colour upon the prominent points. This operation is to be repeated frequently; and as the work advances the quantity of colouring matter is to be diminished, until finally it is spread over the face-place in a thin film, which only dims the brightness of the plate. The surfaces at this stage must be rubbed firmly together to make the points of contact visible, and the higher points will become slightly brightened, while the other parts are left more or less in shade. If too small a quantity of colouring matter be used at first, it will be difficult to form a just conception of the general state of the surface, as the prominent points will alone be indicated, whereas the use of a large quantity of colouring matter in the latter stages would destroy the delicacy of the test the face-plate affords. The number of bearing points which it is desirable to establish on the surface of the work depends on the use to which the surface is to be applied; but whether it is to be finished with great elaboration, or otherwise, the bearing points should be distributed equally over the surface. Face-plates, or planometers, as they are sometimes termed, are supplied by most of the makers of engineering tools. Every factory should be abundantly supplied with them, and also with steel straight-edges; and there should be a master face-plate and a master straight-edge for the sole purpose of testing, from time to time, the accuracy of those in use.

Q. Is the operation of surfacing, which you have described, necessary in the case of all slide-valves?

A. Yes; and in fitting the faces of a D valve, great care was, in addition, taken that the valve was not made conical; for unless the back were exactly parallel with the face, it would be impossible to keep the packing from being rapidly cut away. D valves, however, are not much used in modern engines.

Q. When you described the operation of boring the cylinder, you stated that the cylinder, when laid upon its side, became oval; will not this change of figure distort the cylinder face?

A. It is not only in the boring of the cylinder that it is necessary to be careful that there is no change of figure, for it will be impossible to face the valves truly in the case of large cylinders unless the cylinder be placed on end, or internal props be introduced to prevent the collapse due to the cylinder's weight. It may be added that the change of figure is not instantaneous, but becomes greater after some continuance of the strain than it was at first, so that in gauging a cylinder to ascertain the difference of diameter when it is placed on its side, it should have lain some days upon its side to ensure the accuracy of the operation. In fitting all engines they should be supported as far as possible in the same way that they are to be supported in when set to work.

Q. How is any flaw in the valve or cylinder face remedied?

A. Should a hole occur either in the valve, in the cylinder, or any other part where the surface requires to be smooth, it may be plugged up with a piece of cast-iron, as nearly as possible of the same texture. Bore out the faulty part, and afterwards widen the hole with an eccentric drill, so that it will be of the least diameter at the mouth. The hole may go more than half through the iron; fit then a plug of cast-iron roughly by filing, and hammer it into the hole, whereby the plug will become riveted in it, and its surface may then be filed smooth. Square pieces may be let in after the same fashion, the hole being made dovetailed, and the pieces thus fitted will never come out.

Q. What is the best material for valve faces?

A. Much trouble is experienced with every modification of valve face; but cast-iron working upon cast-iron is, perhaps, the best combination yet introduced. Formerly the practice was to pin brass faces on the cylinder, allowing the valve to retain its cast-iron face. Some makers employed brass valves and others pinned brass on the valves, leaving the cylinder with a cast-iron face. No doubt much of this action was caused by the steam being superheated. Speculum metal and steel have been tried for the cylinder faces, but only with moderate success. In some cases the brass got into ruts; but the most prevalent affection was a degradation of the iron, owing to the action of the steam, and the face assumed a granular appearance, something like loaf-sugar. This action showed itself only at particular spots, and chiefly about the angles of the port or valve face. At first the action was slow; but when once the steam had worked a passage for itself, the cutting away became very rapid, and in a very short time it was impossible to prevent the engine from heating when stopped, owing to the leakage of steam through the valve into the condenser. Malleable iron pipes were sometimes used, but they were speedily worn out by oxidation, and the scales of rust which were carried on by the steam scratched the valves and cylinders.

Q. Will you explain the method of case-hardening the parts of engines?

A. The most common plan for case-hardening consists in the insertion of the articles to be operated upon among horn or leather cuttings, bone dust, or animal charcoal, in an iron box provided with a tight lid, which is then put into a furnace for a period answerable to the depth of steel required. In some cases the plan pursued by the gunsmiths may be employed with convenience. The article is inserted in a sheet-iron case amid bone dust, often not burned; the lid of the box is tied on with wire, and the joint luted with clay; the box is heated to redness as quickly as possible and kept half an hour at a uniform heat; its contents are then suddenly immersed in cold water. The more unwieldly portions of an engine may be case-hardened by prussiate of potash—a salt made from animal substances, composed of two atoms of carbon and one of nitrogen, and which operates on the same principle as the charcoal. The iron is heated in the fire to a dull red heat, and the salt is either sprinkled upon it or rubbed on in a lump, or the iron is rubbed in the salt in powder. The iron is then returned to the fire for a few minutes, and finally immersed in water. By some persons the salt is supposed to act unequally, as if there were greasy spots upon the iron which the salt refused to touch, and the effect under any circumstances is exceedingly superficial; nevertheless, upon all parts not exposed to wear, a sufficient coating of steel may be obtained by this process. In the best modern engines, however, steel is generally used for the working parts and steel castings are used for the framing.

Q. What is the composition of the brass used for engine bearings?

A. The brass bearings of an engine are composed principally of copper and tin. A very good brass for steam-engine bearings consists of old copper 112 lbs., tin 12½ lbs., zinc 2 or 3 oz.; and if new tile copper be used, there should be 13 lbs. of tin instead of 12½ lbs. A tough brass for engine work consists of 1½ lb. tin, 1½ lb. zinc, and 10 lbs. copper; a brass for heavy bearings, 2½ oz. tin, ½ oz. zinc, and 1 lb. copper. There is a great difference in the length of time brasses wear, as made by different manufacturers; but the difference arises as much from a different quantity of surface, as from a varying composition of the metal. Brasses should always be made strong and thick, as when thin they collapse upon the bearing and increase the friction and the wear.

Q. How is Babbit's metal for lining the bushes of machinery compounded?

A. Babbit's, or soft, metal for lining bushes is largely employed in the bearings of marine and locomotive engines and other machinery: it is composed of 1 lb. of copper, 1 lb. regulus of antimony, and 10 lbs. of tin, or other similar proportions, the presence of tin being the only material condition. The copper is first melted, then the antimony is added, with a small portion of tin—charcoal being strewed over the surface of the metal in the crucible to prevent oxidation. The bush or article to be lined, having been cast with a recess for the soft metal, is to be fitted to an iron mould, formed of the shape and size of the bearing or journal, allowing a little in the size for the shrinkage. Drill a hole for the reception of the soft metal, say ½ to ¾ inch diameter, wash the parts not to be tinned with a clay wash to prevent the adhesion of the tin, wet the part to be tinned with alcohol, and sprinkle fine sal-ammoniac upon it; heat the article until fumes arise from the ammonia, and immerse it in a kettle of Banca tin, care being taken to prevent oxidation. When sufficiently tinned, the bush should be soaked in water, to take off any particles of ammonia that may remain upon it, as the ammonia would cause the metal to blow. Wash with pipe-clay, and dry; then heat the bush to the melting point of tin, wipe it clean, and pour in the metal, giving it sufficient head as it cools; the bush should then be scoured with fine sand, to take off any dirt that may remain upon it, and it is then fit for use. This metal wears for a longer time than ordinary gun-metal, and its use is attended with very little friction. If the bearing heats, however, from the stopping of the oil hole or otherwise, the metal will be melted out. A metallic grease, containing particles of tin in the state of an impalpable powder, would probably be efficient as a substitute for the lining of metal just described.

Q. Can you state the composition of any other alloys that are used in engine work?

A. The ordinary range of good yellow brass that files and turns well is about 4½ to 9 ounces of zinc to the pound of copper. Flanges to stand brazing may be made of copper 1 lb., zinc ½ oz., lead ⅜ oz. Brazing solders, when stated in the order of their hardness, are:—three parts copper and one part zinc (very hard); eight parts brass and one part zinc (hard); six parts brass, one part tin, and one part zinc (soft). A very common solder for iron, copper, and brass consists of nearly equal parts of copper and zinc. Muntz's metal consists of forty parts zinc and sixty of copper. Any proportions between the extremes of fifty parts of zinc and fifty parts copper, and thirty-seven zinc and sixty-three copper, will roll and work at a red heat, but forty zinc to sixty copper are the proportions preferred. Bell-metal, such as is used for large bells, consists of 4½ ounces to 5 ounces of tin to the pound of copper; speculum metal consists of from 7½ ounces to 8½ ounces of tin to the pound of copper.

ERECTION OF ENGINES.

Q. Will you describe the method pursued in erecting oscillating engines?

A. The columns here are of wrought-iron, and in the case of small engines there is a template made of wood and sheet-iron, in which the holes are set in the proper positions, by which the upper and lower frames are adjusted; but in the case of large engines, the holes are set off by means of trammels. The holes for the reception of the columns are cast in the frames, and are recessed out internally; the bosses encircling the holes are made quite level across, and made very true with a face plate; and the pillars, which have been turned to a gauge, are then inserted. The top frame is next put on, and must bear upon the collars of the columns so evenly that one of the columns will not be bound by it harder than another. If this point be not attained, the surfaces must be further scraped until a perfect fit is established. The whole of the bearings in the best oscillating engines are fitted by means of scraping, and on no other mode of fitting can the same reliance be placed for exactitude.

Q. How do you set out the trunnions of oscillating engines, so that they shall be at right angles with the interior of the cylinder?

A. Having bored the cylinder, faced the flange, and bored out the hole through which the boring-bar passes, put a piece of wood across the mouth of the cylinder, and jam it in, and put a similar piece in the hole through the bottom of the cylinder. Mark the centre of the cylinder upon each of these pieces, and put into the bore of each trunnion an iron plate, with a small indentation in the middle to receive the centre of a lathe, and adjusting screws to bring the centre into any required position. The cylinder must then be set in a lathe, and hung by the centres of the trunnions, and a straight-edge must be put across the cylinder mouth and levelled, so as to pass through the line in which the centre of the cylinder lies. Another similar straight-edge, and similarly levelled, must be similarly placed across the cylinder bottom, so as to pass through the central line of the cylinder; and the cylinder is then to be turned round in the trunnion centres, the straight-edges remaining stationary, which will at once show whether the trunnions are in the same horizontal plane as the centre of the cylinder, and if not, the screws of the plates in the trunnions must be adjusted until the central point of the cylinder just comes to the straight-edge, whichever end of the cylinder is presented. To ascertain whether the trunnions stand in a transverse plane, parallel to the cylinder flange, it is only necessary to measure down from the flange to each trunnion centre; and if both these conditions are satisfied, the position of the centres may be supposed to be right. The trunnion bearings are then turned, and are fitted into blocks of wood, in which they run while the packing space is being turned out. Where many oscillating engines are made, a lathe with four centres is used, which makes the use of straight-edges in setting out the trunnions superfluous.

Q. Will you explain how the slide-valve of a marine engine without link motion is set?

A. Place the crank in the position corresponding to the end of the stroke, which can easily be done in the shop with a level or plumb-line; but in a steam vessel another method becomes necessary. Draw the transverse centre line, answering to the centre line of the crank-shaft, on the sole-plate of the engine, or on the cylinder mouth if the engine be of the direct-action kind; describe a circle of the diameter of the crank-pin upon the large eye of the crank, and mark off on either side of the transverse centre line a distance equal to the semi-diameter of the crank-pin. From the point thus found, stretch a line to the edge of the circle described on the large eye of the crank, and bring round the crank-shaft till the crank-pin touches the stretched line; the crank will thus be set at either end of its stroke. When the crank is thus placed at the end of the stroke, the valve must be adjusted so as to have the amount of lead, or opening on the steam side, which it is intended to give at the beginning of the stroke; the eccentric must then be turned round upon the shaft until the notch in the eccentric-rod comes opposite the pin on the valve-lever on which it works and falls into gear. Mark upon the shaft the situation of the eccentric, and put on the catches to drive the eccentric, supposing it to be loose upon the shaft and formed with balance weights. The same process must be repeated for going astern, shifting round the eccentric to the opposite side of the shaft, until the rod again falls into gear. In setting valves, regard must, of course, be had to the kind of engine, the arrangement of the levers, and the kind of valve employed; and in any general instructions it is impossible to specify every modification in the procedure that circumstances may render advisable.

Q. Is a similar method of setting the valve adopted when the link motion is employed?

A. Each end of the link of the link motion has the kind of motion communicated to it that is due to the action of the particular eccentric with which that end is in connection. In that form of the link motion in which the link itself is moved up or down, there is a different amount of lead for each different position of the link, since to raise or lower the link is tantamount to turning the eccentric round on the shaft. In that form of the link motion in which the link itself is not raised or lowered, but is susceptible of a motion round a centre in the manner of a double-ended lever, the lead continues uniform. In both forms of the link motion, as the stroke of the valve may be varied to any required extent while the lap is a constant quantity, the proportion of the lap relatively to the stroke of the valve may also be varied to any required extent, and the amount of the lap relatively with the stroke of the valve determines the amount of the expansion. In setting the valve when fitted with the link motion, the mode of procedure is much the same as when it is moved by a simple eccentric. The first thing is to determine if the eccentric rods are of the proper length, and this is done by setting the valve at half-stroke and turning round the eccentric, marking each extremity of the travel of the ends of the rods. The valve attachment should be midway between these extremes; and if it is not so, it must be made so by lengthening or shortening the rods. The forward and backward eccentric rods are to be adjusted in this way, and this being done, the engine is to be put to the end of the stroke, and the eccentric is to be turned round until the amount of lead has been given that is desired. The valve must be tried by turning the engine round to see that it is right at both centres, for going ahead and also for going astern. In some examples of the link motion, one of the eccentric rods is made a little longer than the other, and the position of the point of suspension or point of support powerfully influences the action of the link in certain cases, especially if the link and this point are not in the same vertical line. To reconcile all the conditions proper to the satisfactory operation of the valve in the construction of the link motion, is a problem requiring a good deal of attention and care for its satisfactory solution; and to make sure that this result is attained, the engine must be turned round a sufficient number of times to enable us to ascertain if the valve occupies the desired position, both at the top and bottom centres, whether the engine is going ahead or astern. This should also be tried with the starting handle in the different notches, or, in other words, with the sliding block in the slot or opening of the link in different positions.

MANAGEMENT OF MARINE ENGINES.

Q. What are the most important of the points which suggest themselves to you in connection with the management of marine engines, especially as regards the safety and preservation of the boilers and machinery and the preparations against accidents?

A. The attendants upon engines should prepare themselves for any casualty that may arise, by considering possible cases of derangement, and deciding in what way they would act should certain accidents occur. The course to be pursued must have reference to particular engines, and no general rules can therefore be given; but every marine engineer should be prepared with the measures to be pursued in the emergencies in which he may be called upon to act, and where everything may depend upon his energy and decision.

Q. What is the first point of a marine engineer's duty?

A. The safe custody of the boilers He must see that the feed is maintained, being neither too high nor too low, and should enter in the log-book the pressure of steam, number of revolutions of the engine, and any other particulars which have to be recorded. The economical use of the fuel is another matter which should receive particular attention. If the coal is very small, it should be wetted before being put on the fire. Next to the safety of the boiler, the bearings of the engine are the most important consideration. These points, indeed, constitute the main parts of the duty of an engineer, supposing no accident to the machinery to have taken place.

Q. If the eccentric catches or hoops were disabled, how would you work the valve?

A. If the eccentric catches or hoops break or come off, and the damage cannot readily be repaired, the valve may be worked by attaching the end of the starting handle to any convenient part of the other engine, or to some part in connection with the connecting rod of the same engine.

Q. What would you do if a crank pin broke?

A. If the crank pin breaks in a paddle-vessel with two engines, the other engine must be made to work one wheel. In a screw vessel the same course may be pursued, provided the broken crank is not the one through which the force of the other engine is communicated to the screw. In such a case the vessel will be as much disabled as if she broke the screw shaft or screw.

Q. Will the unbroken engine, in the case of disarrangement of one of the two engines of a screw or paddle vessel, be able of itself to turn the centre?

A. It will sometimes happen, when there is much lead upon the slide valve, that the single engine, on being started, cannot be got to turn the centre if there be a strong opposing wind and sea;

the piston going up to near the end of the stroke, and then coming down again without the crank being able to turn the centre. In such cases, it will be necessary to turn the vessel's head sufficiently from the wind to enable some sail to be set; and if once there is weigh got upon the vessel the engine will begin to work properly, and will continue to do so though the vessel be put head to wind as before.

Q. What should be done if a crack shows itself in any of the shafts or cranks?

A. If the shafts or cranks crack, the engine may nevertheless be worked with moderate pressure to bring the vessel into port; but if the crack be very bad, it will be expedient to fit strong blocks of wood under the main working parts to prevent the cylinder bottom or cover from being knocked out, should the damaged part give way. The same remark is applicable when flaws are discovered in any of the main parts of the engine, whether they be malleable or cast iron; but they must be carefully watched, so that the engines may be stopped if the crack is extending further. Should fracture occur, the first thing obviously to be done is to stop the engines; and should there be much weigh on the vessel, the steam should at once be thrown on the reverse side of the piston, so as to counteract the pressure of the paddle wheel.

Q. Have you any information to offer relative to the lubrication of engine-bearings?

A. The best mode of lubrication would be to have an oil pump, to send oil to all the important bearings both to lubricate and cool them, with return pipe to pump. But failing this a mechanical oil-cup may be employed. A ratchet wheel is fixed upon a little shaft which passes through the side of the oil-cup, and is put into slow revolution by a pendulum attached to its outside, and in revolving it lifts up little buckets of oil and empties them down a funnel upon the centre of the bearing. Instead of buckets a few short pieces of wire are sometimes hung on the internal revolving wheel, the drops of oil which adhere on rising from the liquid being deposited upon a high part set upon the funnel, and which, in their revolution the hanging wires touch. By this plan, however, the oil is not well supplied at low speeds, as the drops fall before the wires are in the proper position for feeding the journal. Another lubricator consists of a cock or plug inserted in the neck of the oil-cup, and set in revolution by a pendulum and ratchet wheel, or any other means. There is a small cavity in one side of the plug which is filled with oil when that side is uppermost, and delivers the oil through the bottom pipe when it comes opposite to it.

Q. What are the prevailing causes of the heating of bearings?

A. Bad fitting, deficient surface, and too tight screwing down. Sometimes the oil hole will choke, or the syphon wick widely employed for conducting the oil from the oil cup into the central pipe leading to the bearing will become clogged with mucilage from the oil. In some cases bearings heat from the existence of a cruciform groove on the top brass for the distribution of the oil, the effect of which is to leave the top of the bearings dry. In the case of revolving journals the plan of cutting a cruciform channel for the distribution of the oil does not do much damage; but in other cases, as in beam journals, for instance, it is most injurious, and the brasses cannot wear well wherever the plan is pursued. The right way is to make a horizontal groove along the brass where it meets the upper surface of the bearing, so that the oil may be all deposited on the highest point of the journal, leaving the force of gravity to send it downwards. This channel should, of course, stop short a small distance from each flange of the brass, otherwise the oil would run out at the ends.

Q. If a bearing heats, what is to be done?

A. The first thing is to relax the screws, slow or stop the engine, and cool the bearing with water, and if it is very hot, then hot water may be first employed to cool it, and then cold. Oil with sulphur intermingled is then to be administered, and as the parts cool down, the screws may be again cautiously tightened, so as to take any jump off the engine from the bearing being too slack. The bearings of direct-acting screw engines require constant watching, as, if there be any disposition to heat manifested by them, they will probably heat with great rapidity, from the high velocity at which the engines work. Every important bearing of a direct-acting screw engine should have a cock of water laid on to it, which may be immediately opened wide should heating occur; and it is advisable to work the engine constantly, partly with water, and partly with oil applied to the bearings. The water and oil are mixed by the friction into a species of soap, which both cools and lubricates, and less oil moreover is used than if water were not employed. It is proper to turn off the water some time before the engine is stopped, so as to prevent the rusting of the bearings. In modern engines an oil-pipe is led to each important bearing.

MANAGEMENT OF LOCOMOTIVES.

Q. What are the chief duties of the engine-driver of a locomotive?

A. His first duties are those which concern the safety of the train; his next those which concern the safety and right management of the engine and boiler. The engine-driver's first solicitude should be relative to the observation and right interpretation of the signals; and it is only after these demands upon his attention have been satisfied that he can look to the state of his engine.

Q. As regards the engine and boiler, what should his main duties be?

A. The engineer of a locomotive should constantly be upon the footboard of the engine, so that the regulator, the whistle, or the reversing handle may be used instantly if necessary; he must see that the level of the water in the boiler is duly maintained, and that the steam is kept at a uniform pressure. In feeding the boilers with water, and the furnaces with fuel, a good deal of care and some tact is necessary, as irregularity in the production of steam will often occasion priming, even though the water be maintained at a uniform level; and an excess of water will of itself occasion priming, while a deficiency is a source of obvious danger. The engine is generally furnished with three gauge cocks, and water should always come out of the second gauge cock, and steam out of the top one when the engine is running; but when the engine is at rest, the water in the boiler is lower than when in motion, so that when the engine is at rest, the water will be high enough if it just reaches to the middle gauge cock. In all boilers which generate steam rapidly, the volume of the water is increased by the mingled steam, and in feeding with cold water the level at first falls; but it rises on opening the safety valve, which causes the steam in the water to swell to a larger volume. In locomotive boilers, the rise of the water-level due to the rapid generation of steam is termed 'false water.' To economise fuel, the link motion, or other valve motion, should be adjusted to the load, and the blast pipe should be worked with the least possible contraction; and at stations the damper should be closed to prevent the dissipation of heat.

Q. In starting from a station, what precautions should be observed with respect to the feed?

A. In starting from a station, and also in ascending inclined planes, the feed water is generally shut off; and therefore before stopping or ascending inclined planes, the boiler should be well filled up with water. In descending inclined planes an extra supply of water may be introduced into the boiler, and the fire may be fed, as there is at such times a superfluity of steam. In descending inclined planes the regulator must be partially closed, and it should be entirely closed if the plane be very steep. The same precaution should be observed in the case of curves, or rough places on the line, and in passing over points or crossings.

Q. In approaching a station how should the supply of water and fuel be regulated?

A. The boiler should be well filled with water on approaching a station, as there is then steam to spare, and additional water cannot be so conveniently supplied when the engine is stationary. The furnace should be fed with small quantities of fuel at a time, and the feed should be turned off just before a fresh supply of fuel is introduced. The regulator may, at the same time, be partially closed; and if the blast pipe be a variable one, it will be expedient to open it widely while the fuel is being introduced, to check the rush of air in through the furnace door, and then to contract it very much so soon as the furnace door is closed, in order to recover the fire quickly. The proper thickness of coke upon the grate depends upon the intensity of the draught; but in heavily loaded engines it is usually kept up to the bottom of the fire-door. Care, however, must be taken that the coke does not reach up to the bottom row of tubes so as to choke them up. The fuel is usually disposed on the grate like a vault; and if the fire-box be a square one, it is heaped high in the corners, the better to maintain the combustion.

Q. How can you tell whether the feed pumps are operating properly?

A. To ascertain whether the pumps are acting well, the pet cock must be turned, and if any of the valves stick they will sometimes be induced to act again by working with the pet cock open, or alternately open and shut. Should the defect arise from a leakage of steam into the pump, which prevents the pump from drawing, the pet cock remedies the evil by permitting the steam to escape.

Q. What precautions should be taken against priming in locomotives?

A. Should priming occur from the water in the boiler being dirty, a portion of it may be blown out; and should there be much boiling down through the glass gauge tube the stop cock may be partially closed. The water should be wholly blown out of locomotive boilers three times a week, and at those times two mud-hole doors at opposite corners of the boiler should be opened, and the boiler be washed internally by means of a hose. If the boiler be habitually fed with dirty water, the priming will be a constant source of trouble.

Q. What measures should the locomotive engineer take, to check the velocity of the train, on approaching a station where he has to stop?

A. On approaching a station the regulator should be gradually closed, and it should be completely shut about half a mile from the station if the train be a very heavy one: the train may then be brought to rest by means of the brakes. Too much reliance, however, must not be put upon the brakes, as they sometimes give way, and in frosty weather are nearly inoperative. In cases of urgency the steam may be thrown upon the reverse side of the piston, but it is desirable to obviate this necessity as far as possible. At terminal stations the steam should be shut off earlier than at roadside stations, as a collision will take place at terminal stations if the train overshoots the place where it ought to stop. There should always be a good supply of water when the engine stops, but the fire may be suffered gradually to burn low towards the conclusion of the journey.

Q. What is the duty of an engine man on arriving at the end of his journey?

A. So soon as the engine stops it should be wiped down, and be then carefully examined: the brasses should be tried, to see whether they are slack or have been heating; and, by the application of a gauge, it should be ascertained occasionally whether the wheels are square on their axles, and whether the axles have end play, which should be prevented. The stuffing-boxes must be tightened, and the valve gear examined, and the eccentrics, if not forged on, be looked at to see that they have not shifted on their axles, though this defect will be generally intimated by the irregular beating of the engines. The tubes should also be examined and cleaned out, and the ashes emptied out of the smoke-box through the small ash door at the end. If the engine be a six-wheeled one, with the driving wheels in the middle, it will be liable to pitch and oscillate if too much weight be thrown upon the driving wheels; and where such faults are found to exist, the weight upon the driving wheels should be diminished. The practice of blowing off the boiler by the steam, as is always done in marine boilers, should not be permitted as a general rule in locomotive boilers when the tubes are of brass and the fire-box of copper; but when the tubes and fire-boxes are of iron, there will not be an equal risk of injury. Before starting on a journey, the engine man should take a summary glance beneath the engine—but before doing so he ought to assure himself that no other engine is coming up at the time. The regulator, when the engine is standing, should be closed and locked, and the link should be secured in mid position, and the tender break screwed down; the cocks of the oil cups should at the same time be shut, but should all be opened a short time before the train starts.

Q. What should be done if a tube bursts in the boiler?

A. When a tube bursts, a wooden or iron plug must be driven into each end of it, and if the water or steam be rushing out so fiercely that the exact position of the imperfection cannot be discovered, it will be advisable to diminish the pressure by increasing the supply of feed water. Should the leak be so great that the level of the water in the boiler cannot be maintained, it will be expedient to drop the bars and quench the fire, so as to preserve the tubes and fire-box from injury.

Q. If any of the working parts of a locomotive break or become deranged, what should be done?

A. Should the piston rod or connecting rod break, or the cutters fall out or be clipped off—as sometimes happens to the piston cutter when the engine is suddenly reversed upon a heavy train—the parts should be disconnected, if the connection cannot be restored, so as to enable one engine to work; and of course the valve of the faulty engine must be kept closed. If one engine has not power enough to enable the train to proceed with the blast pipe full open, the engine may perhaps be able to take on a part of the carriages, or it may run on by itself to fetch assistance. The same course must be pursued if any of the valve gearing becomes deranged, and the defects cannot be rectified upon the spot.

Q. What are the most usual causes of railway collisions?

A. Probably fogs and inexactness in the time kept by the trains. Collisions have sometimes occurred from carriages having been blown from a siding on to the rails by a high wind; and the slippery state of the rails, or the fracture of a brake, has sometimes occasioned collisions at terminal stations. Collision has also repeatedly taken place from one engine having overtaken another, from the failure of a tube in the first engine, or from some other slight disarrangement; and collision has also taken place from the switches having been accidentally so left as to direct the train into a siding, instead of continuing it on the main line. Every train now carries fog signals. These are detonating packets, which are fixed upon the rails in advance or in the rear of any train that, whether from getting off the rails or otherwise, is stopped upon the line. The signals are exploded by the wheels of any approaching train.

Q. What other duties of an engine-driver are there deserving attention?

A. They are too various to be all enumerated here, and they also vary somewhat with the nature of the service. One rule, however, of universal application, is for the driver to look after matters himself, and not delegate to the stoker the duties which the person in charge of the engine should properly perform. Before leaving a station, the engine-driver should assure himself that he has the requisite supply of coke and water. Besides the firing tools and rakes for clearing the tubes, he should have with him in the tender a set of signal lamps and torches, for tunnels and for night, detonating signals, screw keys, a small tank of oil, a small cask of tallow, and a small box of waste, a coal hammer, a chipping hammer, some wooden and iron plugs for the tubes, and an iron tube-holder for inserting them, one or two buckets, a screw jack, wooden and iron wedges, split wire for pins, spare cutters, some chisels and files, a pinch bar, oil cans and an oil syringe, a chain, some spare bolts, and some cord, spun yarn and rope.

CHAPTER XI.

AIR AND GAS ENGINES.

GENERAL PRINCIPLES.

Q. Having now disposed of the subject of the steam engine in its various forms, will you state the qualities and prospects of other thermo-dynamic motors which may be used as alternative sources of power?

A. The only other thermo-dynamic motors which have created any permanent interest, or obtained much attention, are air engines and gas engines, and of each of these kinds of engines, numerous varieties have been presented.

Q. What are the essential points of difference between air engines and gas engines?

A. The most material is, that in the air engine the heat is communicated to the air from some external source, in much the same way in which heat is communicated to the water in a steam boiler by a fire; whereas in the gas engine the heat is injected into the engine in the form of gas, and, being mixed with the proper proportion of air, and ignited within the cylinder, it generates heat and consequently power. There are some forms of engine, however, which do not properly fall under either definition. But they are not of sufficient importance to require special notice here.

Q. You have already stated that the specific heat of air is ·2377, that of water being 1, so that an amount of heat which would raise a pound of water 1 degree would raise a pound of air 4·207 degrees.

A. Yes, that is the specific heat of air under constant pressure, or as it is often more briefly stated in figures, it is ·238. The specific heat of air under a constant volume is ·169.

Q. Why are these amounts different?

A. When air is heated in a vessel which hinders its volume from enlarging, there is no consumption of heat, as a consequence of that enlargement, required to keep the temperature up; whereas if the pressure be kept constant, the volume must be increased when heat is applied, and the larger figure quoted as the specific heat represents the heat necessary to be imparted both to maintain the temperature and satisfy the enlargement. The difference of ·069 between the two specific heats is in reality latent heat.

Q. What is the general principle on which thermo-dynamic motors act?

A. All substances successively exposed to two different temperatures will necessarily generate power, and in the production of that power there will be heat consumed of equivalent value to the power generated. The greater the extremes of temperature the larger will be the proportion of heat transformed into power. Those substances therefore are the most suitable for the generation of power which can be subjected to the greatest extremes of temperature without practical inconvenience. In the steam engine the extremes of temperature, or the difference between the temperature of the water in the boiler and that of the atmosphere, or of the vapour in the condenser, is not very great, and the consequence is that the larger part of the heat is not transformed into power at all, but is wasted—passing off in the form of waste steam if a high-pressure engine, or of hot water if a condensing engine. In air or gas engines, greater extremes of temperature may be employed, and such engines appear therefore to be more suitable for the economical generation of power.

Q. Why may not temperatures equally high to those used in air or gas engines be employed in the case of steam engines?

A. Because in the case of saturated steam a very high temperature also implies a far higher pressure than it would be convenient to use; whereas, if the steam be not saturated but superheated, a limit is soon reached at which the boiler is so much corroded internally by the superheated steam, and the internal surfaces of the cylinder and valves are rendered so difficult to keep in working order, or to lubricate efficiently, that very little progress can be made in the use of high temperatures, if steam be employed as the thermo-dynamic medium. In air or gas engines, however, the cylinder can be kept cool by a water jacket or otherwise—no doubt with a considerable loss of power; but not such a loss as would occur in a steam engine that made use of such an expedient, where the power would be nearly all lost.

Q. Is there the same corrosive action from the use of high temperatures, if saturated steam be employed?

A. No. But the pressure increases so rapidly with the temperature that an impediment is soon reached in the great strength of engine and boiler it is necessary to employ to obtain any appreciable benefit from the elevation of temperature. Thus saturated steam of 100 lbs. per square inch has a temperature of 328 degrees Fahrenheit. With a temperature of 358 degrees the pressure rises to 150 lbs.; with a temperature of 382 degrees to 200 lbs., and so on—the pressure increasing more rapidly than the temperature—until a limit of pressure is reached, beyond which it is not convenient to go, and yet without any such high temperature having been attained as will realise appreciable benefit from that source.

Q. You have not stated why a water-jacket involves less waste in a gas engine than in a steam engine.

A. Because the gas or air is not condensed in the same way that the steam would be. The film of air next the jacket is cooled down, but it prevents the access of the adjoining film, and thus the bulk of the air remains hot although the film next the cylinder is cooled.

Q. Do air or gas engines offer any other advantage beyond that of enabling higher temperatures to be employed?

A. One great impediment to the successful use of air engines has been the difficulty of heating the air; for air is a bad conductor of heat, and the heating surfaces heretofore employed to heat the air in such engines have soon been worn out. But by the injection of a certain amount of combustible gas among the air within the cylinder, which gas is afterwards ignited or exploded by suitable arrangements, and so turned into heat, an external heating surface is rendered unnecessary, and one great impediment to the use of thermo-dynamic engines employing high temperatures has thus been surmounted.

Q. Could not something in the way of thermo-dynamic action be accomplished by the production of cold? If two temperatures are all that is needed for the generation of power, may not the earth be used as the source of heat, and some artificial source of cold be employed to produce the necessary lower extreme of temperature?

A. That does not appear to be a very promising expedient. Cold is merely the absence of heat, and it is reckoned that at 461·2° below the zero of Fahrenheit's scale, a point is reached at which there is no heat at all. This point is what is called the *absolute* *zero of temperature* ; and it constitutes a useful natural datum in dealing with physical questions. But no such degree of cold has yet been practically produced. Any considerable approach to it is a work of difficulty even on the experimental scale, and is altogether unattainable by the ordinary expedients employed in engineering practice. While, however, any incursion into negative temperatures is difficult and must be limited to a narrow sphere, a high positive temperature may easily be reached by the aid of combustion, and the indication therefore to be fulfilled is, while using the ordinary temperature of the atmosphere as the inferior limit of the scale, to employ as high a temperature for the superior limit as can be conveniently adopted in practice.

Q. You have already stated that the heating power of a pound of coal is sufficient to raise 1lb. of water through 14,000° Fahr. or 14,000 lbs. of water through 1° Fahr.

A. That is the quantity given by some experimentalists, while others give the quantity as 14,500, and that upon the whole seems to be the preferable figure to employ. There are 7000 grains in 1 lb. avoirdupois, so that the equivalent of a grain of coal will be 2·071 thermal units, or 1598·812, or say 1600, foot-pounds.

Q. Can you tell what power should be producible by a given air or gas engine when you know the quantity of heat consumed, and the extremes of temperature—supposing there to be no loss from leakage or friction?

A. Yes, that can be told without difficulty. The proportion of heat converted into power will be determined by taking the difference of absolute temperatures between the highest and the lowest, and dividing by the highest temperature, also reckoned from the absolute zero of temperature.

Q. Will you illustrate this law by an example?

A. If a be the temperature of a boiler reckoned from absolute zero, and b be the temperature of the condenser reckoned also from that point, the fraction of the entire heat received by the boiler, which will be converted into power will be $\frac{a-b}{a}$. Now it is clear that if $a = b$ or if the temperature of the boiler and condenser be the same, the value of $\frac{a-b}{a}$ becomes equal to 0, showing that none of the heat is in such case utilised as power. Whereas if a be taken larger and larger while b remains the same, the fraction approaches more and more nearly to 1 or unity, showing that the more the higher temperature is increased, the more nearly the whole heat is transformed into power. Now if a grain of coal produces as much heat as if all turned into power would raise 1600 lbs. a foot high, the power produced in a perfect engine by the expenditure of each grain of coal will be represented by the expression $\frac{1600\,(a-b)}{a}$, supposing that the principle of expansion is carried to its utmost limit, that the heat generated by the coals has all been absorbed by the boiler, that there is no leakage of heat or fluid, and no loss of power from friction. Suppose that the steam used were of 14 atmospheres, the temperature of which is 387° Fahr., and further suppose the temperature of the condenser to be 80° Fahr., the temperature of the steam above the point of absolute zero will in such case be 848·2° Fahr. and of the condenser, 541·2 Fahr. The power produced by the engine will be $\frac{1600\,(848{\cdot}2^\circ - 541{\cdot}2)}{848{\cdot}2}$ = 579 lbs. raised 1 foot high by the combustion of a grain of coal.

Q. How does this consumption compare with that in some of the most economical existing engines?

A. The duty of some of the best Cornish engines is 120 millions of pounds raised 1 foot high by the consumption of a bushel or 94 lbs. of Welsh coal. A grain of coal will at this rate raise 182·37 lbs. 1 foot high. The actual steam engine therefore does not do one-third of the work indicated as possible by the theoretical steam engine, and in air and gas engines precisely the same shortcomings occur.

Q. Will you repeat this calculation as applied to an air or gas engine working at a higher temperature than the steam engine?

A. Suppose the temperature in the heating vessel to be 740° Fahr., and the temperature of the discharge 220° Fahr. Then adding to each temperature 461·2° for the range between the zero of Fahr. and the absolute zero, we have as the resulting absolute temperatures 1201·2° for the higher, and 681·2° for the lower. Pursuing the same process as before $\frac{1600(1201{\cdot}2^\circ - 681{\cdot}2^\circ)}{1201{\cdot}2^\circ}$ = 692 lbs. raised 1 foot high, by the combustion of each grain of coal in an air engine having a temperature in the air boiler of 740°, a temperature in the exhaust pipe of 220° Fahr., and cutting off at one-fourth of the stroke. The performance of such an engine should be nearly four times better than the ascertained performance of the best steam engine as used for pumping water. But nothing approaching to such an efficiency in air or gas engines has been reached in practice.

Q. How does the performance of a Cornish pumping-engine compare with that of the best marine engines?

A. A good marine engine will work with a consumption of 1·7 lb. of coal per horse-power per hour = 11900 grains. The horse-power is 33,000 foot-pounds per minute, or 1,980,000 foot-pounds per hour. Dividing the total foot-pounds per horse-power per hour by the total number of grains of coal consumed to generate this power, we have 1,980,000 divided by 11900 = 166·38, which is the foot-pounds generated in a marine engine by a grain of coal. This is a worse result than that reached in the case of the Cornish engine, where the foot-pounds obtained from a grain of coal were 182·37.

Q. Is there no loss of effect in an air or gas engine from the considerable power required to work the pump by which the air is compressed and sent into the air boiler or cylinder?

A. There is no loss from this cause, as the power thus consumed is afterwards recovered. Thus if we suppose the pump to be impervious to heat, the increase of temperature which the air acquires by compression will be retained by it, and if we suppose that the air without receiving any increase of heat in the air boiler escapes into a cylinder, and urges the piston with the same measure of expansion that it had previously undergone of compression, it would issue from the cylinder at its original temperature and pressure, and the power produced by the cylinder would exactly balance that consumed by the pump. We may therefore discard the consideration of the pump, in estimating the theoretical power of an air engine, since power is neither gained nor lost by it, and the effective power is wholly that due to the increase of pressure, or of volume produced by increase of temperature.

Q. As a degree centigrade is 1·8 times greater than a degree Fahr., must not the mechanical equivalent of a degree centigrade be greater in the same proportion?

A. That follows as a matter of course. The mechanical equivalent of a centigrade degree is 772 × 1·8 = 1389·6, or say, in round numbers, 1390 lbs. raised through 1 foot.

Q. How do you determine the degree of efficacy with which any thermo-dynamic engine works?

A. By comparing the performance with that of a theoretically perfect engine, or one in which the whole heat is supposed to be turned into power.

Q. If you know the highest and the lowest temperatures in any thermo-dynamic engine, can you tell what the theoretical performance will be, or the performance cleared of such incidental sources of loss as friction, imperfect combustion, leakage of heat, and other things of that kind?

A. Yes, it is easy to tell what the performance should be, supposing the engine to be perfect. The difference between that and the actual performance reveals the amount of imperfection.

Q. Taking then the temperatures in centigrade degrees, will you state how you proceed to ascertain the theoretical performance of an engine?

A. From the temperature of the source or boiler subtract the temperature of the condenser. Divide the remainder by the sum of the temperature of the source and 274, and multiply the quotient by the total heat communicated to the engine per minute expressed in the number of degrees through which it would raise one pound of water. Finally, multiply this product by 1390. The result is the number of pounds which the engine should raise a foot high in the minute, and this divided by 33,000 gives the horse-power. The temperatures are all taken in centigrade degrees.

Q. What is the temperature of an ordinary boiler furnace?

A. About 3000° Fahr.

Q. And how much is air expanded by heating?

A. About $\frac{1}{490}$th part of its bulk at 32° for every degree of increased temperature. A cubic foot of air at 32° Fahr. becomes two cubic feet at a temperature of $32 + 490 = 522°$ Fahr., its pressure remaining the same as at first. If its volume remain the same its pressure is doubled.

Q. What will be the new volume acquired by a cubic foot of air at 32° when heated to a temperature of 3000 Fahr.—its pressure remaining unaltered?

A. It will be $\frac{3000}{490} + 1 = 7{\cdot}1$ cubic feet.

Q. If its volume be kept the same, what will its pressure be?

A. If the pressure was one atmosphere to begin with, it will be 7 atmospheres when heated to 3000°, or six additional atmospheres will be added to the first.

Q. If air be expanded by heat so as to fill a larger space than before without any increase of pressure, how can power be generated or expended in such a case?

A. By setting back the atmosphere through a certain space, when if the heat be withdrawn the air will again contract, and the return of the atmosphere into the space whence it had been expelled will generate power.

Q. Have any gas engines been constructed upon this principle?

A. Yes, Brown's vacuum engine patented in 1823, Otto's original form of gas engine, and many others. But the plan has fallen into disuse.

Q. If the temperature of air of the atmospheric density entering the pump of a gas engine be 50° Fahr., and if the air be compressed into one-fourth of its bulk, what will its temperature be?

A. The temperature of the air when compressed will be found to be about 440° Fahr., and its pressure 106 lbs. per square inch. If the volume of the cylinder be to that of the pump as 4 is to 3, then to dismiss the air at atmospheric pressure the temperature must be so increased as to enlarge 3 volumes into 4.

Q. What is the general law which determines the pressure, temperature, and volume in such cases?

A. It was long ago shown by Poisson and Laplace that the heat produced by compression is the same as if the elasticity varied in the proportion of that power of the density whose index is the ratio of the two specific heats. That ratio is 1·408. The relation is expressed by the formula $\frac{t'}{t} = \frac{V^{k-1}}{V'}$, t and t' being the temperatures, and V and V' the corresponding volumes, while k is the ratio of the specific heat under a constant pressure to that under a constant volume. If instead of wanting to know the temperature of the compressed air we want to know its pressure, that may be deduced from the formula

$$\frac{P'}{P} = \left(\frac{V}{V'}\right)^{k}$$

The temperatures are reckoned from absolute zero. P and V are the pressure and temperature before compression, and P' and V' are the pressure and temperature after compression. The power or work absorbed is represented by the formula

$$W = PV\frac{1}{k-1}\left\{\left(\frac{V}{V'}\right)^{k-1} - 1\right\}$$

Q. In what way does a gas engine act?

A. There are a good many variations in the mode of action, but the ordinary mode is as follows:—Into a cylinder—generally a horizontal one—a mixture of air and coal gas is admitted, the proportions usually being about 1 of gas to 10 or 12 of air. This mixture is usually more or less compressed by the piston, or by a separate pump, and at a certain point of the stroke, it is ignited either by electricity or by an external light applied to a touch-hole or by some other method. An explosion is the result which propels the piston in much the same way as a shot is propelled in a gun, and the force thus imparted being communicated to the crank turns the engine. The pressure produced by the explosion is about 5 atmospheres in the older class of engines without antecedent compression. But the maximum pressure manifestly depends upon the amount of compression the explosive charge has received, prior to its ignition. For every 500° Fahr. generated by the combustion the initial pressure will be about doubled. To prevent the cylinder and piston from being injured by the high temperature, a water-jacket, or some other expedient of refrigeration is generally adopted. In some cases the vapour of petroleum or other liquid hydro-carbon is used instead of coal gas, and carbonic-oxide gas, which is much cheaper than coal gas, has also occasionally been employed. Gas engines are still complex and heavy relatively with the power generated, notwithstanding the large amount of inventive effort drawn into this particular field. But it may be expected that these faults will be gradually corrected, though at present their magnitude is such as to restrict the use of the motor to the smallest class of engines in which the avoidance of the necessity of a stoker presents the greatest inducement to their adoption.

Q. What are the desiderata in a good thermo-dynamic motor?

A. Besides being safe and noiseless and equable in its motion it should be light, occupy little space, and be inexpensive both to purchase and to maintain. One obvious necessity involved in such conditions is that the engine shall run fast and work with a good pressure. But a gas-explosion engine must not run so fast that the speed of the piston will overrun the speed of ignition, and even where this result does not ensue time must be given for thorough intermixture and complete combustion. In some gas-engines it has been found that not one-fourth of the heating effect of the gas has been got, and the low result has been imputed to the loss of heat through the sides of the cylinder, owing to the water-jacket. But another important factor is the imperfect combustion of the gaseous charge, partly in consequence of dissociation within the cylinder, and partly from the deficient time afforded to make the combustion complete.

HISTORICAL ACCOUNT.

Q. Without going further at present into the principles of action and the main features in the structure of air and gas engines, will you recapitulate the principal steps of improvement in their past history so as to afford the means of understanding how the system arose, what has been the course of its past progress, and what are its tendencies and prospects in the future?

A. The extent of ground which must be gone over in such a retrospect is necessarily very great, and the individual notices of different projects must be correspondingly brief and oracular. But as a sequel to this narrative I shall endeavour to set forth the most important points for investigation in connection with the present inquiry, and to indicate the most promising lines of research which future effort and ingenuity can pursue.

Q. What were the original forms of air or gas engine employed, and at what dates were they introduced?

A. A gun from which a ball is projected by the combustion of gunpowder fired within the barrel may be taken as the primary form of air or gas engine, and such a device is traceable to a remote antiquity. The fuel or gunpowder, though solid when introduced into the gun, becomes gaseous on ignition. The ball answers to the piston; and in old guns the ignition was effected by applying a light to a touch-hole as is usually done in gas engines at the present time. Fire-arms are at least as old as the time of Moses, seeing that they are prohibited in the code of Gentoo laws which are traceable to as remote a date. Several of the contrivances described in Hero's 'Spiritalia,' 130 years before the Christian era derive their motive force from heated air, and the Æolopile of Hero is believed to have been in use for domestic purposes in the times of the Saxons. Cardan describes a smoke-jack with two sails as a motor. Before 1605 the steam gun and also the air gun had been invented by M. Bourgeois, a native of Lisieux in France, and are described by Rivault in his 'Elements of Artillery' published in 1608. In 1678 the Abbé Hautefeuille proposed to use gunpowder for raising water, and in 1682 instead of gunpowder to work an engine he proposed to use the vapour of alcohol, which was to be generated and condensed as in a still. In 1687 Papin showed experiments before the Royal Society of London illustrative of his plan of producing a vacuum within the cylinder of his engine by the explosion of gunpowder. But he afterwards abandoned this method, as he found that one-fifth of the air remained after the explosion and that consequently half the effect was lost. The project of working an engine by gunpowder has often been revived—among others by Cartwright the inventor of the power loom at the close of the last century, and such an engine could be made to work. But the fuel employed would be too costly for extended use. The explosive property of coal gas when mixed with air has long been known and had been painfully illustrated at a very early date by the explosions of fire-damp in coal mines. When the use of gas became general for purposes of illumination, it would be an obvious indication to employ it instead of gunpowder in working small engines as being both safer and less costly. Instead of gas any of the liquid hydrocarbons could be employed.

Q. Will you give some of the early examples of such application?

A. One such example is afforded by the patent (No. 1,833) granted to John Barber in 1791, in which the expedients employed in modern gas engines are used for the production of power. Into a metallic retort heated by a fire, coal oil or other combustible is introduced, the smoke or vapour from which is brought by a compressing pump into another vessel called an exploder, and meeting there a stream of compressed air brought in by another pump, ignition takes place on the application of a light at the mouth of the exploder. The ignited stream is directed upon a wheel formed with buckets like a waterwheel and running at a high velocity, whereby the power is generated. It is provided that a jet of water shall be projected into the ignited gaseous outflow, both to moderate its heat and to increase its energy. The mechanical details of this patent are very imperfect and are badly illustrated and described. But the essential principles of efficient thermo-dynamic action are embodied in it.

Q. What is the next example?

A. The next example is afforded by the patent, granted to Robert Street in 1794 (No. 1,983), for his method of generating an inflammable vapour force by means of liquid, air, fire and flame. This engine has a still closer analogy to a gunpowder engine than the foregoing example. There is a cylinder, the bottom of which is kept hot by a fire, and near the bottom of the cylinder there is a touch-hole. A small quantity of spirits of tar or turpentine is to be poured through a funnel in the hot cylinder, which liquid is instantly converted into inflammable vapour. The piston is then raised by a lever, to admit condensed air, and at the same time a light is raised to the touch-hole, whereby an explosion is produced which generates power. The quantity of tar or turpentine specified as necessary to be used, is 10 drops for each cubic foot of capacity of cylinder. In this patent, as in the previous one, the details are very imperfectly worked out.

Q. When was the use of electricity for igniting the gas first suggested?

A. It is not quite certain; but it was proposed to be used by Lebou, in a patent granted to him in 1801, though in the kind of engine he used there could have been little inducement for the employment of electricity as an igniting agent. He forced air and gas through separate channels into a furnace, where they were burnt, and the piston was propelled by the products of combustion. In 1807, M. Rivaz took out a patent in Paris ('Brevets d'Invention,' tome ix. p. 182) for the propulsion of a carriage, by the explosion of hydrogen gas, by admitting a certain quantity of air and hydrogen, by means of a three-way cock, below the piston of an engine. The explosion was to be effected by one of four methods,—by keeping the base of the cylinder red hot, by the compression of air as in the syringe for igniting tinder, by the use of phosphoretted hydrogen, or by the electric spark. In 1817 Niepce, another Frenchman, took out a patent (No. 4,179) for propelling vessels by means of a gaseous stream, issuing astern produced by the combustion of suitable substances in close cylinders within the vessel. Lycopodium, powdered resin, and powdered coal are mentioned as suitable substances. But a liquid hydrocarbon is that which was adopted. The principle of this contrivance appears to be perfectly sound, and may be expected one day to be brought into successful operation. But the gaseous stream should be cooled by a jet of water, the steam resulting from which would be effectually condensed in the sea, and would help forward the effluent air as in Nicholson's patent of 1806 (No. 2,990).

Q. Is such a principle of propulsion ever likely to come into practical competition with the screw or paddles?

A. I believe so, and although general incredulity will attend such a declaration it is the incredulity of ignorance, which has invariably attended all improvements not yet accomplished, however promising they might appear to those most competent to judge.

Q. What was the nature of Nicholson's patent of 1806?

A. It was an improvement upon the ancient contrivance for blowing air into furnaces by a shower of water which carries down air with it into a pipe, as described in the writings of Lewis Chaptal and other authors of reputation. A jet of steam issuing from the pipe *a* carries air with it into the cone *b b* and issues at *c c*. Water however, introduced by the pipe *d* into the tank *e e* passing through the holes in *c c*, condenses the steam so that air alone is carried forward with the issuing water.

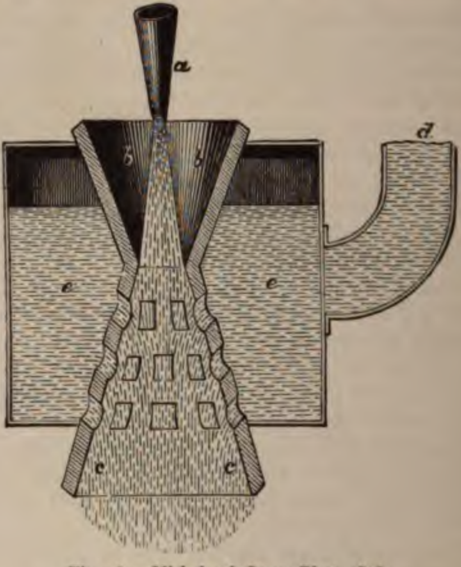


Fig. 163.—Nicholson's Steam Blast, 1806.

Q. The energy of the steam appears to be transferred to the air?

A. Yes. The laws which govern the transformation of energy, had before this time been investigated mathematically by Bernouilli and Euler, and in 1818 a patent was taken out in France by the Marquis Mannoury D'Ectot, in which various forms of apparatus are described for effecting this transformation. One of these is a composite steam-jet resembling the subsequent contrivances of Pelletan, Bourdon, and Delabarre. One of the problems proposed for solution in this patent is, to draw water from wells—not merely from a depth of 33 feet, but from a much greater depth. The manner in which this is proposed to be done is as follows:—Let a chamber *a*, fig. 164, be placed at the height to which it is proposed to raise the water. A pipe *k* descends into the water of the well, and near the bottom of this pipe a non-return valve is placed. From the tank *c* a pipe *d* descends to the sphere *e*, and the point of *d* is turned up to form a jet which enters the pipe *k*. A communication between *a* and *c* is established by an overflow pipe, on the outlet of which there is a non-return valve *i*. Steam having been introduced into the chamber *a*, and its condensation having been effected by water entering from the tank *c*, the pressure of the atmosphere will force the water into the pipe *k k*. Meanwhile the water flowing from the tank *c* through the pipe *d*, and issuing upward at *e*, in a jet of which the *vis viva* is converted into pressure, an extra pressure is created sufficient to overcome the resistance of the column *h n*, and the water flowing through the overflow pipe at *i*, restores to the tank *c* the water before expended.

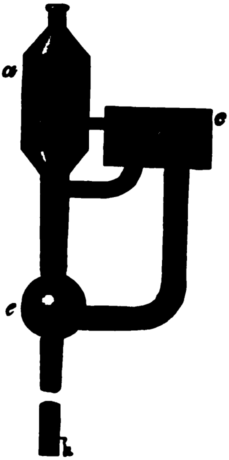


Fig. 164.
Steam-jet Pump, 1818.

Q. Would such an instrument for raising water be useful in practice?

A. It would be very useful in special cases, such for example as in raising sandy or muddy water when establishing deep foundations, in digging wells, or in any case where the valves of ordinary pumps are liable to be gagged or the barrel to be severely worn by the attrition of foreign particles. In steam vessels consequently steam-jet pumps are now widely employed. They eject a large quantity of water in a short time, and are simple and inexpensive in construction, while whatever enters the suction-rose, whether chips, pieces of coal or clinkers, or bits of metal, are sent through indifferently by the steam, the only precaution necessary to keep the pump always effective being to keep the rose clear.

Q. This patent appearing at so early a date, reflects the highest credit upon its author?

A. It does.

Q. It is in reality an anticipation of Giffard's injector, now so widely introduced?

A. Yes. This is illustrated by fig. 165, where *o* is a pipe dipping into a tank *l*, and terminating in the sphere *k*, which communicates by means of the pipe *n* with the chamber *g* into which a jet of steam is conducted which issues through the open pipe *h*.

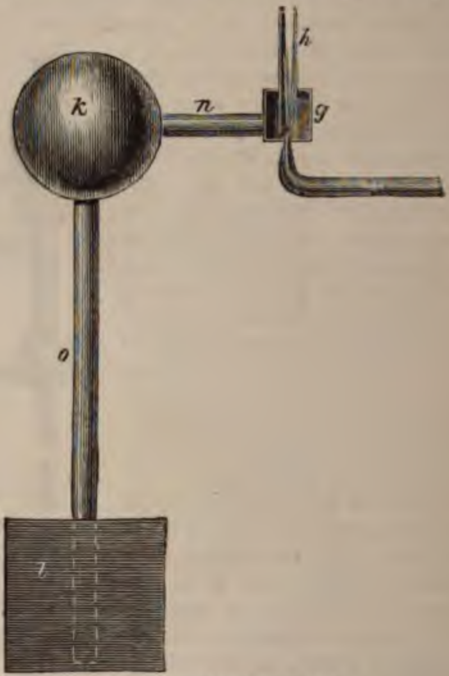
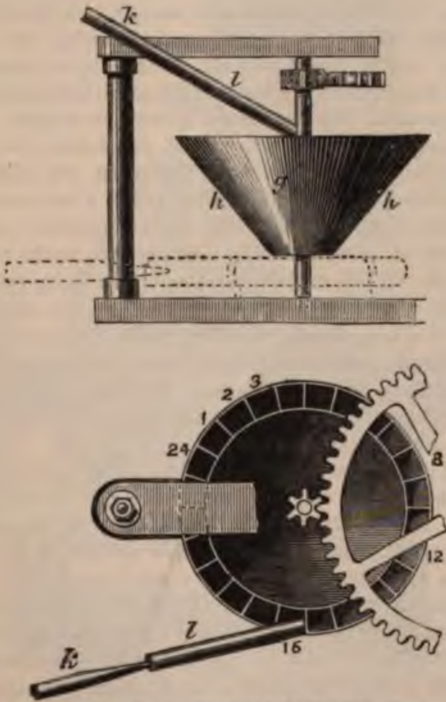


Fig. 165.—Form of Injector in 1818.

The first effect of this jet is, to draw the air out of the sphere *k*, and to cause the water to ascend in the pipe *o*, from the tank *l*, into the sphere *k*, whence it passes through the pipe *n*, into the chamber *g*. The steam-jet there encounters the water, and is condensed by it, and the energy of the steam being communicated to the water, projects it through the pipe *h*, in the same way as is done by a Giffard's injector.

Q. These arrangements are only applicable to the raising of ter. Are there any indicated for the production of circular tion ?

A. Yes, in figs. 166 and 167 a species of danaïde is shown, for production of rotatory motion by a mixture of air and steam. ere are two concentric cones *h h*, which have between them an



Figs. 166 and 167.—Steam and Air Danaïde, 1818.

nular space fitted with 24 spiral pallets or vanes numbering 2, 3, &c., of which the 8th, 16th, and 24th descend to the bottom the annulus, and the others only half-way. The steam-jet *k* is ected into the open pipe *l*, and its energy is communicated to air within that pipe. The energy of the composite current carries downwards between the concentric cones, and impinging on the spiral vanes, it issues at the bottom with little force, its energy having been mostly imparted to the machine. Such a wheel requires to run at a high velocity to get a maximum effect.

Q. What is the next thermo-dynamic contrivance of any importance in order of time?

A. There is a patent (No. 4,537) granted to Robert Stein in 1821 for working an engine with a mixture of steam and the products of combustion. Coal is fed into a close ash-pit, by a fluted roller, and another fluted roller is employed for withdrawing the ashes from the ash-pit. Air is forced into the furnace by a pump, and the products of combustion generate steam in a boiler, and are then used in conjunction with the steam to work an engine. This plan however, though fairly well arranged in the details, did not excite much attention, nor did the coal feeder on the plan of Stein proposed by Mark Isambard Brunel in 1822. They were succeeded by Sir Samuel Brown's gas vacuum engine patented in 1823 with improvements in 1826, from which important results were at one time expected. In this contrivance the motive force was the return of the air into a vacuum produced by the explosion of a mixture of gas and air in a large iron vessel from which the explosion expelled the air. Several gas engines have been constructed upon this principle and have done useful work. But the apparatus is bulky, noisy, and less efficient than where the piston is propelled by the direct force of the explosion.

Q. What is the next example you have to present?

A. The next is the original form of the caloric engine of John Ericsson—a name illustrious in the history of engineering for numerous important inventions. In this project, as in Stein's, the furnace is a close one. The fuel is fed into it through double doors, and the air is blown into it by a blowing-engine, the products of combustion being compelled to enter into intimate contact with the water in the boiler, and the engine is worked by the mixture of those products and the generated steam. A representation of this engine is given in fig. 168, where A is the blowing cylinder, B the piston, and C the piston-rod. D is the ashpit, to which the air is conducted through the pipe E, and F is the furnace. G is a coil of heating pipes, which delivers through the pipe K into the boiler R R, in which there are a number of shelves; and the water, brought in from the tank P through the pipe S, and the valve Q, falling from shelf to shelf among the hot products of combustion, is

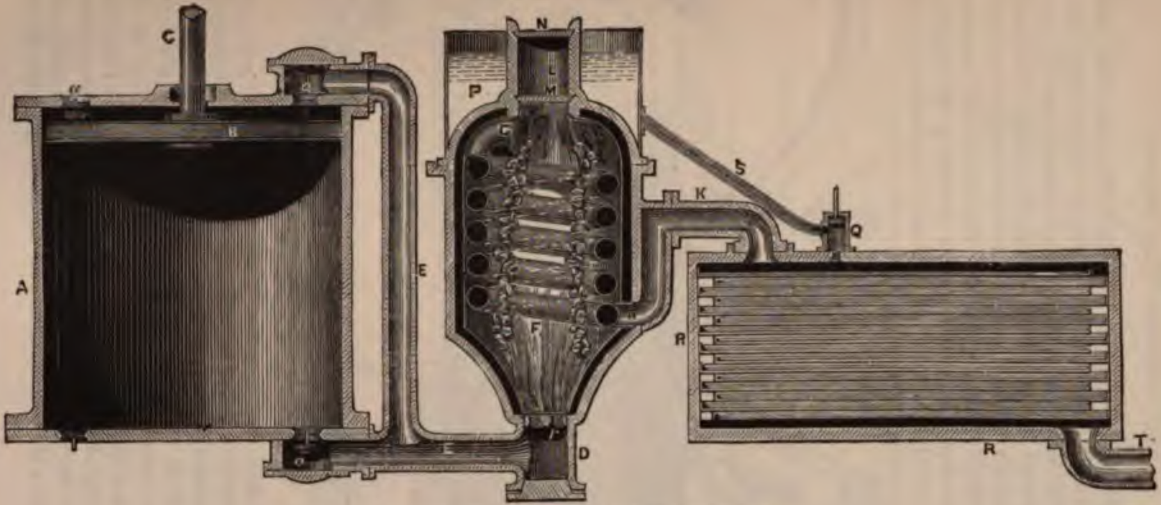


Fig. 168.—Ericsson's original Caloric Engine, 1826.

vaporised. L is a chamber into which the coal is fed, and M and N are two sliding doors, one of which is always shut. *a a* are the inlet and outlet valves of the blowing cylinder, and *n* is the furnace bars. In 1833 Ericsson took out another patent (No. 6,409) for an improved form of his engine, in which he discards the use of water and of the blowing-engine, but introduces the regenerator to recover the waste heat, and applies the fire to the exterior of the cylinder. A representation of Ericsson's engine in the form it had attained before 1867 is given in fig. 169, where A is a horizontal cylinder, in which there are two pistons—one, the driving piston, which is impelled by heated air, and the feeding piston which sends in cold air. B is the furnace, C the driving, and D the feeding piston, the power being generated, and the feeding of the air accomplished, by the differential motion between the two. E is the axis of the fly-wheel F. K is a shaft carrying a lever L, connected with the driving piston by the bar *b*. P P are the outlets for the smoke. O is a lever connected with the feeding piston by the bar

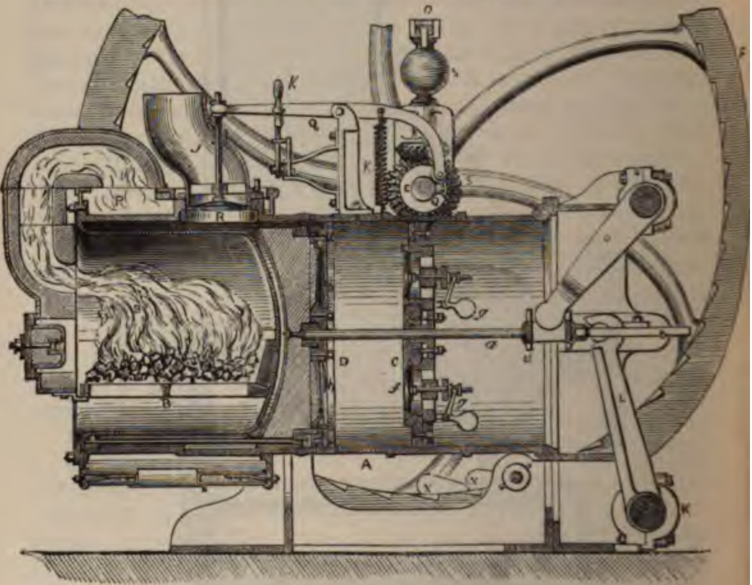


Fig. 169.—Ericsson's Caloric Engine, before 1867.

a, *f f* are valves for the admission of air, pressed shut by the counterweights *g*; *h h* are valves of sheet steel placed in the piston D. There is a space between the working part of the cylinder and the furnace filled with broken brick, through which the air passes, and by which it is equably heated; *j* is an eduction pipe to let out the hot air after its force has been spent, and R is the eduction valve governed by the cam Q; *k* is a spring to keep the lever up to the cam; S is the governor, and X X are ratchets to enable the fly-wheel to be more easily turned round by hand in starting the engine. Ericsson's caloric engine, of small powers, has come into pretty extensive use both in America and in Europe.

Q. Were there any other patents of importance taken out in 1826?

A. None of importance. There is one in this year (No. 5,402) taken out by Erskine Hazard for 'a method of preparing explosive mixtures, and employing them as a moving power for machinery.' But the arrangements are crude, and the principle destitute of novelty. The vapour of alcohol or turpentine is to be mixed with air and exploded through a touch-hole.

Q. What have we in 1827?

A. In that year W. W. Hall, in an ill-digested specification (No. 5,448), proposed to pump the products of combustion from a furnace into a boiler. In the same year the Rev. Robert Stirling and James Stirling patented (No. 5,456) their air-engine, in which the novel principle of a regenerator first appears. In these engines the air was generally heated by a fire applied to the bottom of the cylinder. But it was found that by this arrangement the bottom of the cylinder was soon worn out. The novel feature, however, was the regenerator, consisting of a great number of thin sheets of metal, or layers of wire-gauze, or other minutely subdivided material, through which the air had to pass. When hot air was passed through this material during a stroke of the engine, it emerged cold, having left its heat in the thin metal sheets or wire-gauze; or if sent in the opposite direction cold, it emerged hot, having in its passage taken up the heat again which was before deposited. By the use of the regenerator therefore the heat, which was before dismissed in the exhaust in hot-air engines, was to a great extent recovered and used to assist in heating the cold air of the next stroke. The principle of the regenerator has since been applied to a great variety of purposes in the arts, and may be made service-able in cooling as well as in heating. A popular illustration of the principle is given in the breath-warming instrument, in which the air entering the lungs is warmed by a large area of metallic surface, of which the instrument is composed, and which had been heated by the breath in the previous expiration. It is now known that in any kind of engine a given amount of heat is capable of generating only a corresponding amount of power, and that just in the proportion in which the engine is efficient there will be less and less waste heat dismissed by the exhaust. There will therefore, in the same ratio, be less and less waste heat for a regenerator to recover, and in an engine which worked with air at the temperature of combustion the whole heat will be turned into power, and a regenerator in such an engine would have nothing to do. As the whole tendencies are in favour of higher temperatures however, the regenerator has fallen into disuse. But the recollection of the contrivance will always remain as a splendid specimen of mechanical perspicacity. A regenerator will enable a lower temperature to be used in a heat-engine without much waste. But it is rather a cumbrous apparatus, and has consequently not been widely adopted. The Stirlings took out a patent (No. 8,652) for an improved form of their air-engine in 1840.

Q. Is there any other plan of interest to be mentioned as having been produced during this year?

A. There is the patent (No. 5,530) of W. Parkinson and S. Crosley for 'an improved method of constructing and working an engine for producing power and motion.' In this engine a horizontal cylinder had a plunger within it, called a transferrer, of nearly the same diameter as the horizontal cylinder, and of about half the length. This transferrer could be moved to and fro by a rod, and the effect of such movement was to transfer the air contained within the horizontal cylinder from one end to the other. One end, however, was kept hot, and the other end cold, so that the movement of the transferrer alternately heated and cooled a volume of imprisoned air, and the alternate expansion and contraction of the air acting upon a piston generated power. The amount of power, however, so generated was quite insignificant, and the engine was never practically introduced.

Q. Will you enumerate some of the other plans which have been projected for working engines with the hot products of combustion mixed with steam?

A. It will be impossible to give an exhaustive enumeration as the number is so great. In 1829 Church (No. 5,857) patented a similar arrangement to that of Stein and Brunel, and in America several plans were devised at an early period for sending the products of combustion of the furnace into the water of the boiler. In 1837 a patent (No. 7,303) was taken out in this country on behalf of Phineas Bennett, an American, for an application of this principle—the fuel, as in Ericsson's arrangement, being fed in by means of two sliding shutters. Zander, in 1842 (No. 9,516), proposed a hollow cylinder to feed in the coal. Houston, in 1849 (No. 12,649), used combined steam and hot air to work an engine, the air being sent in among the steam by a pump. Fontaine Moreau, in 1850 (No. 13,111), proposed to generate power by sending steam mixed with the products of combustion into a vibrating vessel partly filled with fusible metal, and Bresson, in 1852 (No. 776), proposed to propel locomotives and also vessels in the water by the action of heated gases acting as a rocket. Sochet, in 1853 (No. 2,768), obtained compressed hot air for working reaction engines and for other purposes by forcing cold air into hot pipes by jets of steam. Imray, in 1853 (No. 1,569), Blanchard, in 1855 (No. 339), and Edwards, in 1855 (No. 1,560)—all proposed to obtain motive power from the products of combustion forced through bent pipes into the water of the boiler, and diffused thereamong by means of perforated plates, the engine being worked by the intermingled gases and steam. In some cases the water was proposed to be diffused among the gases instead of the gases among the water. In 1863, A. Merlanchon (No. 1,449) proposed to transform heat into power by burning fuel under pressure in a close chamber, and, by projecting into this chamber water in a minutely divided state, to generate steam. The conjoint products and steam were employed to work an engine. Partington (No. 2,233) in 1872 proposed to burn coal in a close furnace, into which air was forced, and the fuel was fed in by means of two sliding shutters. The products of combustion entered the boiler and mingled with the steam. In 1874, J. Scott Russell (No. 1,962 and also 4,177) proposed to generate power by using the products of combustion in a boiler as well as the steam, and the two might be used either mixed or separate. These constitute but a portion of the projects for using the products of combustion in a furnace for the generation of power. None of them have come into use, and they are all defective in various respects, chief among which are the arrangements employed for introducing the fuel and getting rid of the clinker. The same disqualifications apply to all or nearly all the plans which have succeeded these.

Q. Returning now more immediately to the subject of air and gas engines, what other early examples of that class of engine have you to notice?

A. In 1826 Gasy Cazalat of Paris took out a patent for producing motive power by exploding a mixture of air and hydrogen gas, and he used the product of the explosion to propel a vessel by causing it to pass through a pipe beneath the water pointing astern. He expected to be able to recover most of the expense of the zinc used in the generation of the hydrogen by the sale of the sulphate of zinc produced. The scheme, however, was a visionary one. The first well-designed and really promising gas engine was that of Lemuel W. Wright, an American settled in London, who in 1833 took out a patent (No. 6,525) in which inflammable gases and air are made to explode in a globular vessel and to work the piston of an engine like a steam engine, the piston being lubricated by water escaping round its periphery, and the cylinder being furnished with a water jacket. In 1835 M. Boucherat patented a method of obtaining motive power by exploding at intervals a combustible material in a close vessel, and in 1837 Riviere and Braithwaite patented in Paris a mode of obtaining motive power from the expansion of air. A regenerator was charged with compressed air by a pump to which pipes were connected which passed through the furnace. These pipes were raised to a red heat and the air was then admitted into them. With the extended heating surface thus obtainable the metal would stand for a much longer time than in Stirling's original arrangement. In 1838 Ambrose Ador patented a method of obtaining motive power by the combustion of hydrogen. In the same year William Barnett (No. 7,615) proposed to obtain motive power by the explosion of gases lighted by a flame contained in a hollow rotating cock. This flame would be put out by the explosion, but would be relighted by a permanent flame outside the engine as the opening in the cock again came round. The flame, it was also stated, might be relighted by platinum. This is the first example of a well-contrived lighting arrangement, afterwards imitated by Hugon and others. The arrangement will be understood by a reference to fig. 170. It is substantially a double touch-hole arrangement, intended to prevent the explosive mixture from blowing back, as when the exterior touch-hole is open that between the cylinder and the barrel of the cock is shut.

Q. Will you enumerate a few other examples of explosive gas engines?

A. In 1840 Demichaelis and Monnier took out a patent in Paris for obtaining motive power from a mixture of hydrogen gas and air, exploded by an electric spark or otherwise; and in 1841 James Johnston (No. 8,841) also proposed to obtain motive power by exploding oxygen and hydrogen in close cylinders. In 1843 Joseph Robinson (No. 9,972) proposed to obtain motive power by exploding the vapour of turpentine or other inflammable vapours or gases, mixed with air, in close vessels; and in the same year James Neville (No. 9,840) proposed to obtain motive power by combining with coal the rough nitrates of potash and soda, the resulting salts being carbonates or subcarbonates, and the liberated gases working an engine. This mixture, indeed, constituted a sort of rough gunpowder,

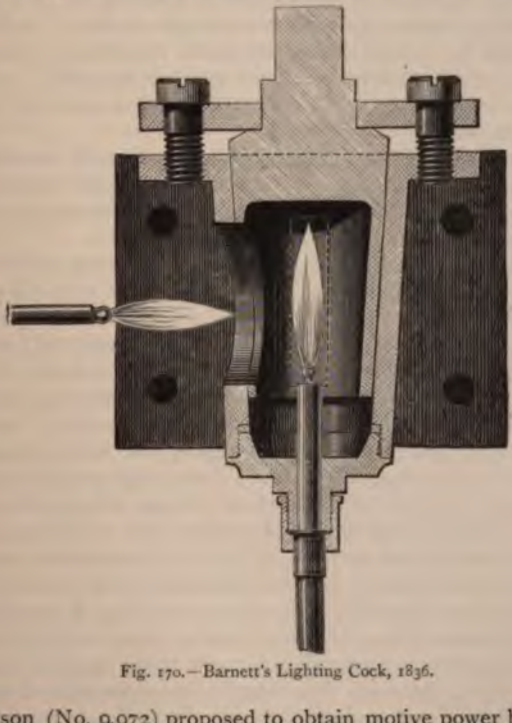


Fig. 170.—Barnett's Lighting Cock, 1836.

but not so explosive. In 1841 T. W. B. Reynolds (No. 10,404) obtained motive power by exploding gas which compressed air, and this air generated power. In 1845 Alexander Gordon (No. 10,545) patented a method of propelling vessels by forcing air into a close furnace, and compelling the smoke to issue below the water at the stern; and by this gaseous stream the vessel was to be propelled. This contrivance, called the 'Fumific Impeller,' never came into use. The principle in its main features is sound, but the details were so faulty that it could not have been got to work. Moreover, the ascent of a vigorous stream of smoke from the water at the stern of a vessel would have been quite inadmissible, and the indispensable antecedent of any such contrivance would be to establish smokeless combustion.

Q. Were none of these numerous plans ever made to answer?

A. No, none of them; and I have by no means enumerated the whole up to this date. The less important I have passed over without notice.

Q. It would be tedious to describe all the plans which have been invented, but perhaps it will be as well if you will give a few more examples.

A. On December 7, 1846, W. H. Fox Talbot patented a method of obtaining motive power from gun-cotton in a cylinder by electricity. Sir James Anderson proposed a similar application. But such a fuel is too expensive except for fancy purposes. In 1850 Edward Dunn patented a caloric engine, but there is nothing new in it. On March 24, 1852, A. M. T. de Montravel patented an air engine in which the air heated by fire was to be used in close cylinders, but liquid or semi-fluid matters were to be interposed between the piston and the air. In 1852 W. Quarterman patented an engine for obtaining power from gunpowder or gun-cotton. The same project has often been reproduced. In 1853 Fabian Wrede (No. 1,648) patented improvements in air engines, consisting chiefly of an arrangement whereby the air was made to pass through numerous holes, and it was thus brought into more efficient contact with the heating and cooling surfaces. In the same year W. E. Newton patented an arrangement whereby the air was compressed before it was heated; and R. Roger compressed air by pistons forced forward by the explosion of gases. This compressed air was to generate the power. W. E. Newton also proposed to use an air engine with hot cylinders and cold cylinders; the hot to be kept hot by a hot jacket, and the cold to be cooled by a water-jacket. The air was to pass from beneath the piston in the hot cylinder to above the piston in the cold cylinder. In the same year J. R. Napier and W. J. M. Rankine (No. 1,416) patented an air engine of which the peculiarity consists in the use of a particular species of plunger, and in heating and cooling the air by sending it into a number of small tubes or cylinders into which small plungers pass. In May 1854, June 1857, and December 1861, Eugène Barsanti and Felix Matteucci (No. 3,270) took out patents for obtaining motive power from explosive gases and detonating compounds. Hydrogen gas and air, it was stated, might be exploded in a cylinder with two pistons. The gases when exploded would drive the pistons forward, and the pistons with suitable rods would impart their motion to machinery. The explosive mixture might be ignited by a constant flame forced forward by a small pump, or a pneumatic fire-producing apparatus might be employed for this purpose. But the charge might also by ignited by the electric spark. In 1854 A. E. L. Bellford (No. 457) proposed to use water as an intermediary for transmitting to the piston the pressure of the exploded gases without transmitting their temperature; also for using liquid carbonic acid as a source of power—a suggestion made several years before by Sir Humphry Davy and by various other persons. In 1856 C. J. B. Torassa patented an arrangement for using hydrogen gas obtained from the decomposition of water in generating power, and in 1857 J. S. Rousselot again patented the same idea. In July 1858 G. Cavaggia and A. Spinelli patented an arrangement for using the gases evolved by the slow combustion of nitrates, fulminates, &c., in the generation of power. In 1859 James Anderson took out a patent (No. 2,767) for obtaining power by the explosion of carbonic oxide in a cylinder. On June 30, 1860, Henry Francis Cohade took out a patent for obtaining power by the explosion of suitable gases, and in the same year Jean Étienne Lenoir (No. 335) patented his gas engine, in which motive power is obtained from a mixture of air and inflammable gas exploded by the electric spark. In 1861 he patented (No. 107) improvements in his gas engine, in which the air and gas are introduced through perforations in a valve which dispose them in alternate strata, and moist steam or mist or spray of water is also introduced to increase the pressure at the moment of explosion. This was no doubt a mistake. The combustion should have been perfected before water was introduced, as premature cooling will prevent much of the gas from being burnt at all. Lenoir's engine was therefore expensive in gas, Nevertheless, it was the first species of gas engine which was practically introduced, and to it others which have been more successful owe their parentage. This engine is represented in Fig.

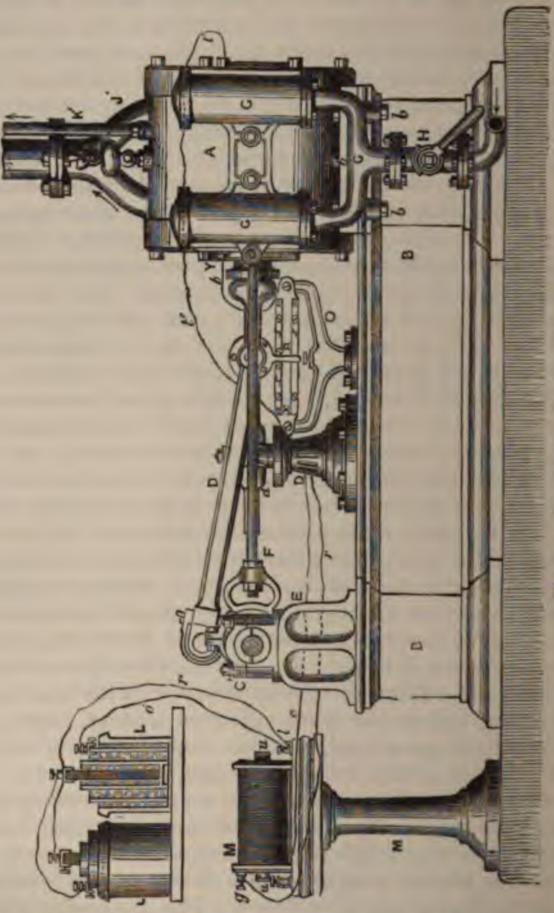


Fig. 171.—Lenoir's Gas Engine, 1860.

171. A is the cylinder; B, the framing; *b*, the holding-down bolts of the cylinder; C′, the crank; D, the forked connecting rod; D′, the guide pillar, and *d*, the guide eye for taking the end of the piston

rod; E is the eccentric which moves the slide valve by which the gas and air are admitted, and there is another similar eccentric and valve on the other side of the engine, to let out the products of combustion. F is the eccentric rod. The cock H admits the gas into the branching pipe G and the distributory vessels G G, whence it is admitted by the slide valve into the cylinder. The products of combustion pass out through similar ports on the other side of the cylinder, and escape through the eduction pipe J′. The water circulating in the water-jacket escapes by the pipe K′. The exploding apparatus is a Ruhmkorff's coil which heats to ignition a small piece of porcelain interposed between the ends of the wires within the explosive mixture. L is the battery; M is the bobbin on which the coil of wire is wound, and *u u* is a core of soft iron placed within it; *l*, *g*, *o*, *o′*, and *r* are wires to communicate the electricity to the exploders. The wire *o*, which answers to the negative pole, is attached to the stand O. The wire *r* which answers to the positive pole is attached to the bar *s*, which is insulated by a sheet of india-rubber, *x*. Y is one of the exploders connected with the insulated bar *s s* by the wires *t t′*, and R is a runner attached to the piston rod by which contact is made and broken. The mixture of air and gas being admitted into the cylinder during a certain portion of the stroke is exploded at some predetermined point, when the piston is pressed by the imprisoned gases to the end of the stroke, and is then forced back to the other end by a repetition of the same operation. Hugon's engine is very similar to Lenoir's, except that in Hugon's the mixture is ignited by a lighted jet of gas instead of by the electric spark.

In 1860 a patent (No. 2,074) was granted to Sir C. W. Siemens for 'Improvements in engines to be worked by the alternate expansion and contraction of steam and other elastic fluids.' An engine of this nature was described in a specification of a patent granted to the same inventor (No. 1,363 of 1860), and is described in the 'Artisan Treatise on the Steam Engine.' But the objection to it was that it was bulky and complex, and that the ends of the cylinders which were to be heated by coal fires were soon burnt out. By the more recent patent these evils were proposed to be surmounted by turning the coal into carbonic oxide by slow combustion in a furnace or gas generator, as has been done in the gas furnaces of Silesia during more than a century, and this gas was to be burnt by means of a number of jets of atmospheric air distributed in such a way as to produce nearly an equal heating effect over the entire surface of the heated vessel. By another arrangement the heat is proposed to be generated by internal instead of external combustion. For this purpose a chamber, which may be lined with platinum or other refractory material, is to be attached to the hot end of each working cylinder. Two pipes, one carrying air and the other gas, which is ignited at the point of junction, supply the heating power necessary to make good the loss of temperature in the fluids propelling the working pistons consequent on their expansion. The carbonic oxide supplied to the engine should, it is stated, be cooled and purified before being used, which in its turn implies bulk and complication. Fig. 172 is a longitudinal section of this engine, with a cross section on the right-hand end and a gas generator at the left-hand end. It will be seen from the cross section that there are five cylinders cast in a piece with the bottom frame, and of which the central cylinder constitutes a gas reservoir, while the other four are working cylinders, the piston rods of which are connected with a wabbling disc, an arm from which turns round the shaft in the same way that a crank would do. There is nothing new in such an arrangement. But it implies many cylinders and much complication, though it can be made to work. This engine is fitted with a regenerator, which, however, is not shown in the figure. The gas generator shown at the left-hand side consists of two cylinders, one set on the top of the other, so that it may be lifted off by the handles, and both are lined with refractory material. At the bottom of this lining there is a grate, to which the coal is fed through a cover at the top, which is set in a sand-bed to prevent the escape of gas. Such an arrangement is quite inadequate for serious work, and on the whole it is certainly not surprising that so crude a production never came into practical use.

Q. What other patents were taken out in 1860 and 1861?

A. F. H. Edwards (No. 2,999) patented an air-engine. M. A. F. Mennons patented an engine in which the air was heated by an internal jet of gas. W. E. Newton patented a compressed air-engine heated by an internal jet of gas. Pierre Hugon patented the use of two platinum wires heated by a jet of gas to effect the explosion in gas-engines; and Louis Simon patented an air-engine which was an imitation of Ericsson's. All these were in 1860. In 1861 J. B. Pascal (No. 166) patented an engine worked by carbonic oxide gas exploded in a cylinder; and F. Million (No. 1,840) patented an engine in which a mixture of air and carbonic oxide

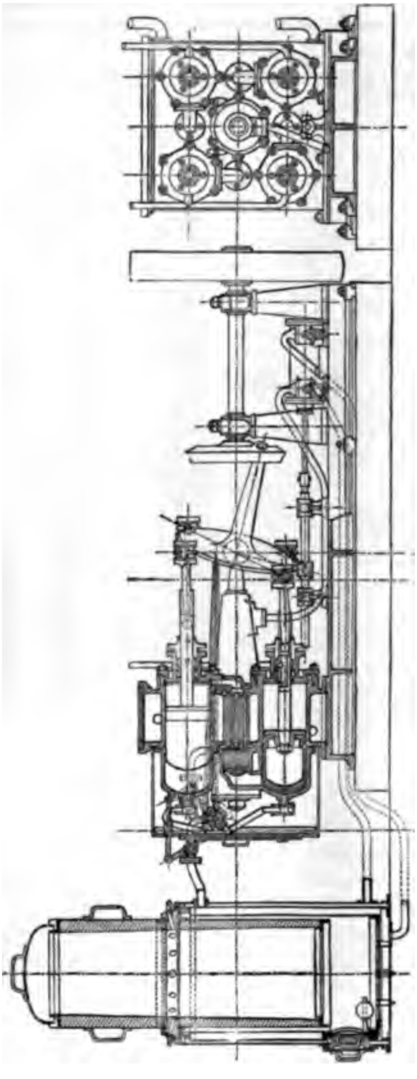


Fig. 172.—Siemen's Steam, Air, and Gas Engine, 1860. Longitudinal and cross sections

are exploded by the electric spark. The carbonic oxide is generated in a close furnace, like an iron furnace, the fuel being fed in through a hopper at the top furnished with double valves.

In 1861 also Philander Shaw (No. 1,818) patented improvements in hot-air engines in which he used plungers kept cool by a small stream of air; Theodore Schwartz (No. 2,797) patented improvements in the details of caloric engines; and Huch and Windhausen patented improvements in caloric engines, in which hot air and the products of combustion were made to work an engine, the furnace being close, and the fuel fed in through a hopper with double valves. Philander Shaw's engine was shown in operation at the Paris Exhibition of 1867.

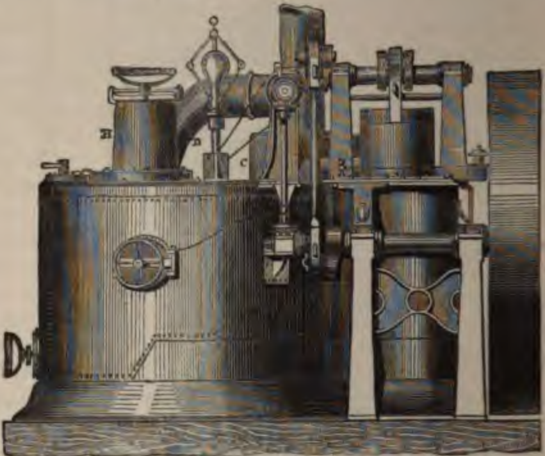
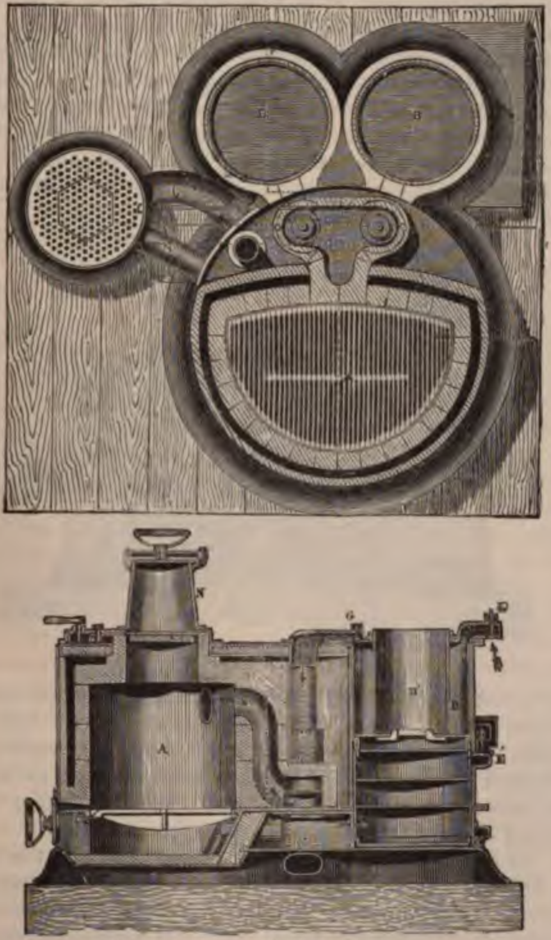


Fig. 173.—Shaw's Air Engine.

Q. What are the special features of that engine?

A. They are represented in figs. 173, 174, 175, and 176. A is the close furnace, into which the fuel is introduced through the hopper H, which is furnished with two sluice valves—one at the mouth, which is usually kept shut, but which is opened when the fuel has to be introduced; and one between the hopper and the furnace, which is shut when the top valve is opened, so as to prevent the hot air shut within the furnace from escaping into the atmosphere. The intermediate valve being shut, and the top valve opened, the opper is filled with fuel, and the top valve being then closed, and he intermediate valve opened, the fuel falls into the furnace without



Figs. 174 and 175.—Shaw's Air Engine.

e loss of more hot air than that which fills the hopper. B B re the cylinders, and B′ a trunk piston or plunger, of which the annular part acts as a compressing pump for sending air into the furnace, while the lower face of the piston is pressed by the hot products of combustion. C is a vessel containing a number of vertical tubes through which the exhausted hot air passes to the chimney, and past which the air forced into the furnace flows so as to absorb the surplus heat; and D″ is a governor. F and G are the inlet and outlet valves of the pump, and E′ the valve for admitting the hot products of combustion to act upon the piston. J, N are communicating pipes between the engine and tubular air-heater or regenerator. The engine exhibited in Paris had two cylinders of 24 inches diameter and 18 inches stroke. The pistons were connected by an overhead beam, and the trunks were 15½ inches diameter. The working pressure was 14 lbs. per square inch. The furnace was formed of boiler plate, lined with two rows of fire-bricks, between which the entering air circulated before coming in contact with the fuel, so as to keep the casing cool.

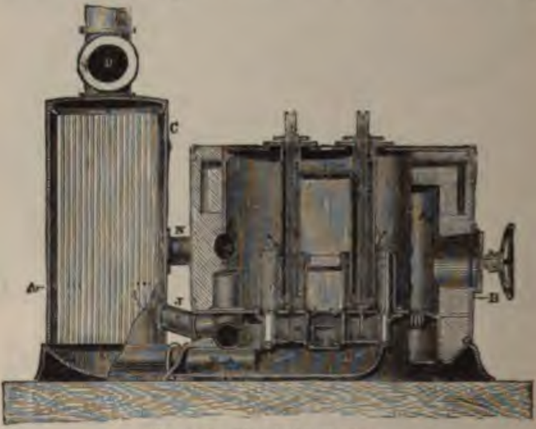


Fig. 176.—Shaw's Air Engine.

Q. As Hugon's engine is so like Lenoir's, except in the lighting being effected by a fixed master light, as in Barnett's, instead of by the electric spark, it will not be necessary to go in any detail into the structure of Hugon's engines. But what have you to say about Otto's, which seem to have superseded the other kinds?

A. The 'Otto' engine is of much the same date as the Lenoir and the Hugon, and it also was shown at the Paris Exhibition of

1867. Lenoir and Hugon's original engines were worked with eight volumes of air to one of coal gas, and Otto's with nine volumes of air to one of gas. The cause of the preference given to Otto's engine is its greater economy of gas. The respective performances of the three engines were ascertained experimentally by Tresca, who found that to generate a force of one horse-power 140 cubic feet of gas per hour were consumed by the Lenoir engine, 85 cubic feet by the Hugon, and 35 by the Otto engine. The absolute pressure generated in the cylinder by the explosion was five atmospheres in the case of the Lenoir and Hugon engines, and from four to six atmospheres in the case of the Otto, so that the cost of maintenance was very high. By the use of carbonic oxide, however, instead of coal gas as the motive agent, this cost may be greatly reduced. But the preparation of the gas will require a man's attention and time; whereas in the case of ordinary gas engines, working with gas from the main, this may be dispensed with. The cost of a man's time, it is needless to say, is a considerable addition to the cost of the motive power in the case of small engines, and no large gas engines have yet been constructed.

Q. What are the special features of the Otto engine?

A. Two forms of the Otto engine have been produced differing very much from one another. In the first form the cylinder was vertical, the piston was of considerable weight, and the energy of the explosion expended itself by shooting up the piston like a shot out of a gun, the cylinder being made of considerable height, so that the energy of the explosion might expend itself without the piston leaving the cylinder. The piston left a vacuum behind it, as in Brown's vacuum engine, and this and the weight of the piston terminated the motion before the piston had gone too far. There were two heavy fly-wheels to equalise the motion, and on the fly-wheel shaft there was a ratchet arrangement which permitted the piston to be shot up without interfering with the motion, but the piston could only get back to the bottom of its stroke by pressing round the ratchet-wheel, and therefore the fly-wheel, with the force due to the weight of the piston and the vacuum beneath it, acting during the whole length of the cylinder from the top to the bottom. This species of engine was noisy and deficient in uniformity of impulse, and about 1876 it was exchanged for another form more resembling Lenoir's and Hugon's. Both of these forms are exhibited in figs. 177 and 178. The old form is not now made, but the new form has been introduced very extensively, and constitutes the prevailing type of gas engine now supplied.

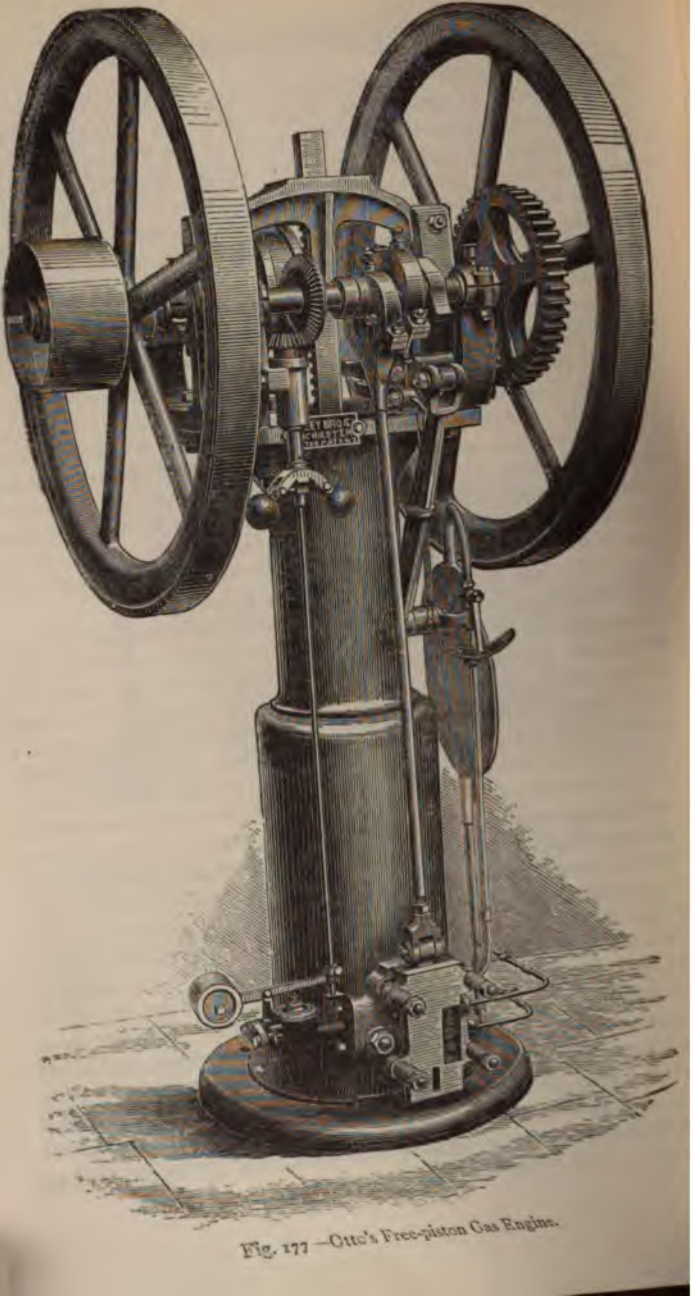


Fig. 177.—Otto's Free-piston Gas Engine.

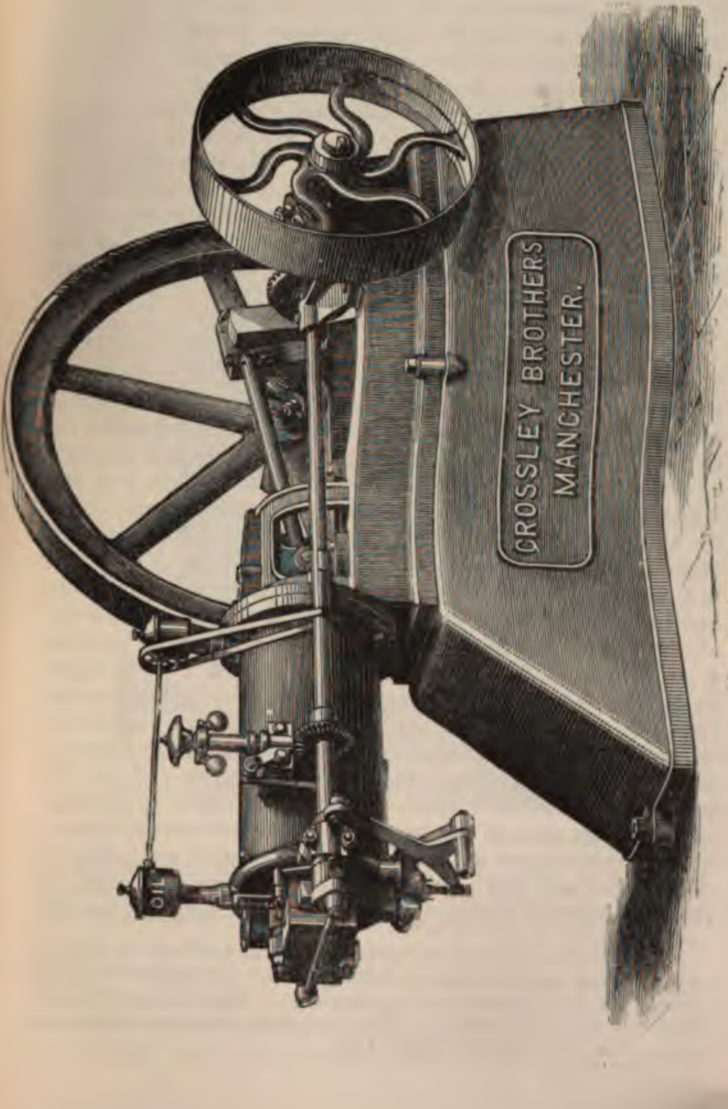


Fig. 178.—Otto's direct-pressure Gas Engine.

Q. Before entering into any practical exposition of the merits of the most prominent engines it will be as well to complete the enumeration of the different plans which have been propounded, with a brief indication of their most essential features. Will you therefore proceed to do this?

A. The operation will be laborious, and involves a good deal of repetition, as identical expedients have been patented again and again. But I know of no other course by which a view of the whole reach of invention in this department of the arts can be commanded. This work of drudgery having been performed, it will become possible to deal with the general question of the merits of this type of thermo-dynamic engine with some approach to confidence.[1]

Q. Advancing then from 1861, what do we find?

A. Omitting some trivial devices, we find that in 1863 W. D. Richards (No. 2,806) patented several improvements in the details of Stirling's or Ericsson's hot-air or caloric engines. In 1866 J. and C. Pratt patented an air engine, in which they expanded the air by heat and contracted it by cold, the air being kept in a state of great concentration. But Stirling and many others had previously done this. In 1868 J. M. Plesner patented an arrangement for obtaining power from atmospheric pressure resulting from a vacuum formed by the expulsive action of flames on air contained in a cylinder, which had been done half a century before by Brown and others, while Otto's engine operating upon this principle was already in use. Caldwell in 1872 (No. 340) proposed to break up a jet of hydrocarbon fluid by projecting upon it a jet of superheated steam, as had often been done and proposed before that time. In 1874 Hirsch (No. 594) proposed to work an engine with the products of combustion of liquid or gaseous fuel, and to use a regenerator as in Stirling's engine. Brayton (No. 432) in 1872 proposed to form an intimate mixture of air and a light hydrocarbon. This mixture was to be stored in a reservoir, under a high but uniform pressure, and a jet of the mixture was ignited in the cylinder, and thus generated power. Fogarty (No. 3,848) in 1873 proposed an arrangement similar to the foregoing, but the inflamed gases were to act upon water in a U tube. Turner (No. 4,088) in 1873 proposed to utilise the direct force of the explosion of gas as well as the indirect force of the vacuum, which could not be done, as whatever was gained by one would be lost by the other; and Julius Hoch (No. 493) in 1874 proposed to work an engine by the ignition of petroleum spray. This engine was shown in operation at South Kensington, but has not come into use. Brayton's engine is represented in fig. 179. It operates upon the principle of continuous combustion, and whereas in common gas engines the power is generated by the explosion of a mixture of gas and air, in this engine the power is generated by the increased bulk of air when heated. There is a reservoir for holding a limited quantity of the gaseous mixture, and a jet of it is burnt under pressure to generate power. Coal gas may be used instead of the vapour of petroleum or other hydro-carbon, and the best proportions for the mixture are said to be twelve volumes of air to one of gas. Referring to fig. 179, A is the cylinder proper of the engine, which is

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[1] It would be impossible in the limits within which these remarks must be confined to deal with the question of furnaces. Yet the furnace is often an essential part of a thermo-dynamic arrangement. Those desiring information on that subject may consult my 'Treatise on Steam, Air, and Gas Engines.' Quarto. Longmans and Co. 1878.—J. B.

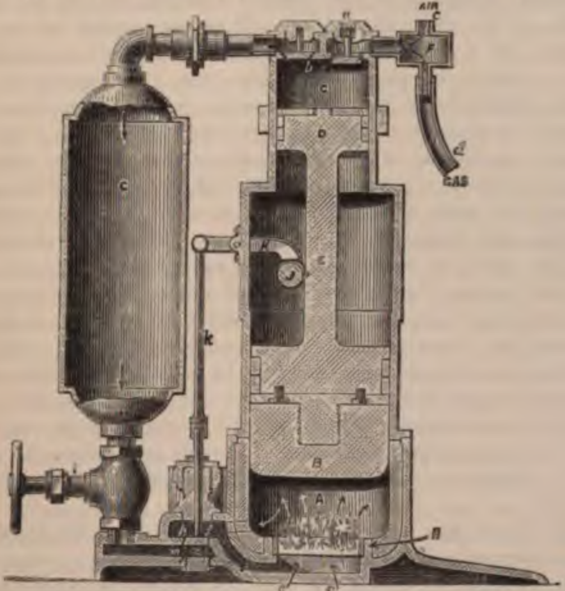

Fig. 179.—Brayton's Petroleum Engine, 1872. Vertical Section.

fitted with a piston B. The piston is protected from the heat by having affixed to it a block of refractory material, and the cylinder is fitted with a water-jacket. The cylinder A, with its piston B, is surmounted by an air-pump C, fitted with a compressing piston D, and the rod E unites both pistons. The air-compressing pump is supplied with a proper induction valve *a*, and eduction valve *b*. F is a chamber provided with two inlets *c* and *d*, one for air and the other for combustible gas or vapour. The movement of the air-pump piston, D, will at each downward stroke draw into the barrel, C, a charge of the gaseous mixture, and on the upward stroke of the piston this charge will be compressed into the reservoir G. In a chamber, H, at the bottom of the cylinder A there are a number of wire-gauze diaphragms, *e*, to prevent the flame from striking back into the reservoir. I is a screw valve, which allows the gaseous mixture to flow into the passage *f*, when the valve *h* is opened at every upstroke of the piston by the cam J, which moves the lever K and the valve rod *k*. The spring *j* causes the valve *h* to close when released from the cam. In starting the engine, a lighted taper is introduced through the exhaust port. A small quantity of the gaseous mixture is kept always burning, but the volume of the flame is enlarged and contracted at each stroke by the valves turning off or on the gas. Should the flame go out, it will not be relighted as in Otto's engine by a master-flame outside. In No. 4,422 of 1876 we have another patent by the same inventor for an improvement in this engine by introducing water into the piston through two hollow piston rods, in which a circulation of water is maintained.

Q. What patents were there taken for gas or vapour engines in 1875?

A. There was a patent (No. 71) granted to G. W. Daimler for 'Improvements in motor engines worked by gas or combustible vapour and air.' Besides the working piston, two other pistons—one on each side of the working piston—were used. These latter pistons, it is directed, are to be loose in the cylinder, and are to be made very light. On the ignition of the explosive mixture the front loose piston will be propelled rapidly to the front end of the cylinder, where it is retained by special means. The gaseous products of the explosion being cooled by their expansion, a partial vacuum will be produced in the cylinder, whereby the working piston, and with it the back loose piston, will be caused by the atmospheric pressure to travel together towards the front end of the cylinder. The working piston moving on while the back loose piston is arrested, a space is left between the two, into which a fresh charge of air and gas is drawn. At the same time, the working piston approaching the front loose piston forces out the products of combustion. Such are the main features of this design. Then there was granted to Smyth and Hunt the patent No. 2,334. Two cylinders are used, one opposite to the other, and, as in the last arrangement, there is to be a loose piston as well as a working piston in each. A partial vacuum will be created by the explosion between the two pistons, into which the next charge will be drawn. There is next the patent (No. 3,221) granted to Francis William Crossley and William John Crossley for 'Improvements in gas motor engines.' The object of these improvements is to provide an efficient spring or cushion for the piston, and to render the action of the governor more effective. A. K. Ryder patents (No. 3,404) his hot-air engine in this year. There is next the patent (3,615) of N. A. Otto for improvements in engines worked by gas and air. The improvements referred to are applicable to the kind of engine in which a piston is propelled without doing work, as exemplified in the patents Nos. 2,098 of 1863, 1,173 of 1864, and 2,959 of 1870, granted to the same inventor. They consist in the substitution for the mechanisms therein described—and shown in fig. 177—of hydraulic apparatus, whereby a liquid like water or oil is made to accomplish the desired alternation of action. This plan was never practically carried out, having been supplanted by the same inventor's engine of the Lenoir type. There is next the patent (No. 4,342) granted to Alexis de Bisschop. The main features of novelty in this engine are a long stroke (ten or more diameters are recommended), no water-jacket, but radiating surfaces of five times greater collective area than the area of the exterior surface of the cylinder. The air and gas pipes are made so long that their mouths where the valves work are removed from the influence of the heat. This completes all that is worth notice in 1875.

Q. What have we in 1876?

A. There is the patent (No. 132) granted to Francis William Crossley for 'Improvements in gas motor engines.' Those improvements have reference chiefly to a mode of moving the valves to start the engine without the necessity of rotating the fly-wheel. Then there is the patent (No. 1,520) granted to Frank Wirth. This invention, it is stated, relates to engines for obtaining motive power from the explosion of gas without noise and at a slight cost. The engines made on this plan, it is stated, are simple in construction, and are susceptible of easy repair. An elongated cylinder is employed, open at one end and fitted with two pistons, as has so often been proposed both before and since. The working piston is connected in the usual way to a crank. The other piston, which is termed the loose piston, has a rod passing through the cylinder cover, and through two friction cheeks mounted on levers in such a manner that they permit the free motion of the piston-rod in one direction, but not in the opposite direction until the cheeks are relieved by an eccentric at a certain appointed part of the stroke. At the side of the cylinder near the middle of its length is the gas-slide, which is worked by a cam on the shaft. In its jacket are provided passages for the ingress and mixture of air and inflammable gas, and of a kindling flame. In the patent 3,370, granted to Sack and Reunert for improvements in gas motor engines, it is claimed that the engine occupies less space than heretofore, and also that it is more uniform in its action. The gas used is to be the vapour of gasoline, petroleum, or other suitable fluid hydrocarbon. There does not appear to be any novelty in the design. The cylinder is provided with a differential piston. The explosion chamber is placed at the side of the cylinder, and is provided with a slide-valve for admitting at each revolution of the driving shaft the required quantity of the explosive mixture, which being inflamed enters the cylinder below the piston, acting on the smaller surface thereof; and before the piston arrives at its highest point a valve allows the mixture to enter above the piston and act on its larger surface. When the piston has completed its stroke, the valve, worked by a link motion, allows the escape of the gases to take place. The cylinder and explosion chamber are surrounded by water. An arrangement is provided for lubricating the piston with distilled water, as also the stuffing-box. The piston-rod is connected with the crank in the usual manner. In the patent 4,987, granted to R. Hallewell, the end of the cylinder is fitted with a perforated plate, through the small orifices in which the gas is forced by a small pump, the object of this arrangement being to make the combustion more gradual, and thus obviate the shock resulting from explosion. In fig. 180 a representation is given of a part of this engine; and in figs. 181, 182, and 183, sections of the admission and igniting valves in different positions: 6 is the perforated plate at the end of the cylinder, and 15 the small gas-pump; 11 is a cam,

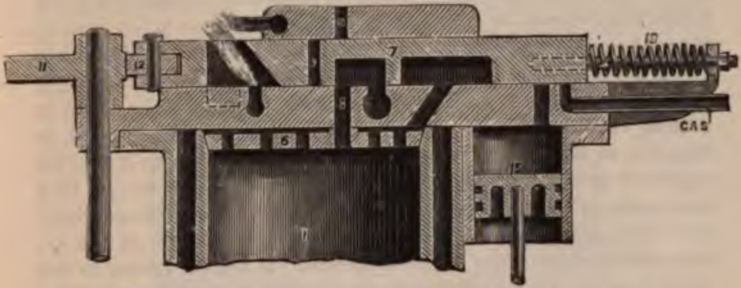

Fig. 180.—Hallewell's Gas Engine, 1876. Horizontal Section through Cylinder and Gas-pump.

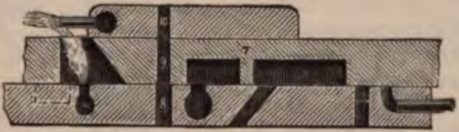

Fig. 181.—Hallewell's Gas Engine, 1876. Horizontal Section through Valve. Position when firing.

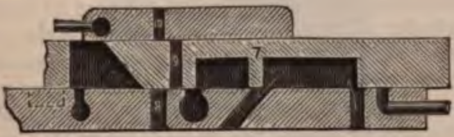

Fig. 182.—Hallewell's Gas Engine, 1876. Horizontal Section through Valve. Position when admitting Gas to Cylinder.

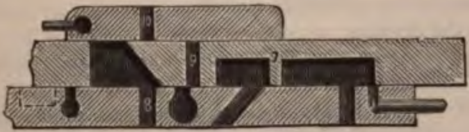

Fig. 183.—Hallewell's Gas Engine, 1876. Horizontal Section through Valve. Position when drawing Air.

and 12 the roller on which it works for propelling forward the valve 7, which is returned by a spring, 13. 8, 9, and 10, when in line, permit the air to enter the cylinder, and upon the air so admitted the jets of gas are forcibly projected by the gas-pump. In the patents 1,961, granted to Lascelles, 3,435, to Simon, and 4,422, to Lake, there is nothing requiring special notice. But the patent 2,081, granted in this year to N. A. Otto, is deserving special attention, as it may be regarded as the first really successful horizontal gas engine that was made, and most of those emanating from other sources which have since appeared are more or less close imitations of the arrangements which Otto here introduced. It will be proper to describe pretty fully this very meritorious engine, as we must recognise it as the pioneer of all that has since been successfully done in this department of the arts. No doubt Lenoir and Hugon both made a gas engine to work, as others had done on the experimental scale before their time; but Otto's engine was the first that was sufficiently economical in its consumption of gas to enable the system to endure. In the annexed cuts 184 and 185, fig. 184 is a longitudinal section of an engine on Otto's improved design, the cylinder A having a piston B connected to the fly-wheel shaft in the manner usual in steam engines, an inlet passage C, controlled by the slide D, and a passage, E, for the emission of the products of combustion closed by a valve F. When the piston is at the end of its in-stroke its inner surface being at *a*, the slide D is in such a position that as the piston begins its out-stroke, air entering by the aperture D^2 passes D and C into the cylinder. When the piston has reached the point *b* the slide has moved so as to admit combustible gas or vapour from the passage G to mix with the entering air, until the piston reaches the point *c*, when the slide has moved back to the position shown, cutting off the gas and air supply, and about to establish a communication between a small gas flame, H, in G^1 and the charge in the cylinder. The combustible gaseous mixture entering the cylinder behind the air previously admitted becomes partially mixed therewith, being thus dispersed more and more towards the piston, as indicated by the dots in the drawing, which represent the combustible particles. Fig. 185 is part plan of another form. The engine being single-acting, the cylinder A is open in front. At its closed back end it has beyond the stroke of the piston a space A^1, preferably of conical form, tapering to the inlet port C, and also communicating by a passage, E, with the valve F, for discharging the products of combustion. At one end of the shaft is the crank K^2, connected by a link, D², to the valve D, which governs the admission of gas and air into the cylinder. When the piston is at the end of its in-stroke, and about to be moved outwards by the momentum of the fly-wheel, then the slide D is in position to admit air through the passage D' and port C into the cylinder, until the piston reaches the point *a*, when the slide attains such a position that combustible gas is drawn in together with air until the piston reaches the end of its out-stroke. The slide having now closed the inlet port C,

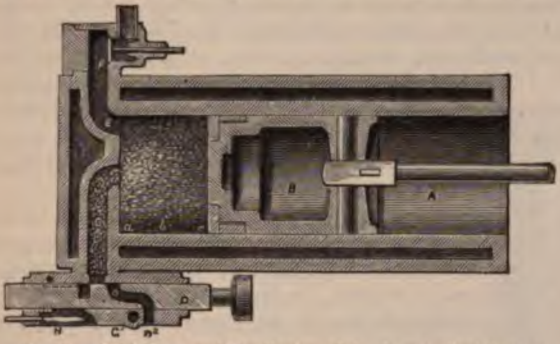

Fig. 184.—Otto's Improved Gas Engine, 1876. Longitudinal Section.

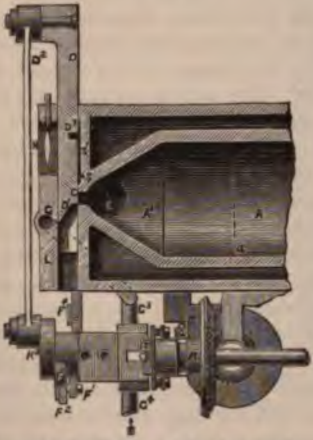

Fig. 185.—Otto's Improved Gas Engine, 1876. Another form. Sectional Plan.

the piston is caused by the momentum of the fly-wheel to perform its in-stroke, compressing the charge of gas and air into the space A^1. The slide now moves so as to admit the gas flame H, igniting the charge, whereby the piston is caused to perform its out-stroke, imparting fresh momentum to the fly-wheel. This momentum again causes the piston to perform its in-stroke, expelling the products of combustion through a valve, which is opened by the lever F^1 F^4 acted on by a cam F^3 driven by the wheel R. The quantity of gas introduced is regulated by the gas-slide P, controlled by a governor Q; L is the valve cover, and G, G^3, and G^4 the gas pipe; S S is the igniting gas. This concludes the patents taken out in 1876.

Q. Will you now enumerate the patents taken out in 1877?

A. Dugald Clerk, of Glasgow, analytical chemist, patented (No. 252) improvements in motive-power engines working with hydrocarbon gas or vapour. It is a special feature of this design that the expanded gases due to the explosion act directly through valves on air or gases, a portion of which they force into a reservoir, instead of acting upon a piston as in other explosion motor engines. The explosion takes place in a chamber between which and the reservoir there is an intermediate chamber, and any convenient engine is worked by the gaseous mixture under the pressure which is in the reservoir. The valves between the explosion chamber and the intermediate chamber, and between the intermediate chamber and the reservoir, may be moved by the gases or by mechanism from the engine. A piston is by preference worked in the explosion chamber for drawing in the supply of gas or vapour and of air for each explosion. The explosion is succeeded by a partial vacuum, which is made to aid in working the engine. The engine is large, and the mechanism is complex, and a better engine has more recently been produced by the same inventor. A. Otto and F. W. Crossley patented (491) 'Improvements in gas motor engines.' One of these improvements is to prevent waste of gas should the engine be brought to rest with the gas-slide open. Another is to take back into the cylinder some of the hot products of combustion when the engine is not required to be worked at full power. Another improvement relates to the construction of the engine slide, and the arrangement of passages therewith for effecting the ignition of the charge in the cylinder after compression. The cover of the main slide D fig. 186 has a small chimney F formed on it, partly below and partly within which a small gas jet G is kept continually burning. The slide has a forked passage C B E formed in it leading to an opening on its inner face, through which the ignition of the charge is effected when the slide is brought into the proper position. Before the slide is brought into this position one branch of the passage is made to communicate with a hole in the cover leading to the chimney, while the other branch communicates with another hole in the cover leading to the atmosphere. Another small passage in the valve establishes a communication between the forked passage and a groove in the slide cover into which a small gas pipe J opens, so that during a certain portion of the stroke of the valve combustible gas will pass into the forked passage, where it will mix with air entering the lower branch. On the forked branch being made to communicate with the flame its charge will be ignited, and on the further motion of the slide, the communication being cut off between the forked passage and the gas jet, it is brought into communication with the inlet port of the cylinder, so as to fire the charge. Just before this takes place, however, the small passage in the slide through which the forked passage is charged is made to communicate with a small passage leading to the interior of the cylinder, so that a portion of the prepared combustible charge in the cylinder will enter the forked passage, pushing before it the gas contained in the small passage in the slide maintaining the combustion in the forked passage, and raising the pressure of the gases therein to that existing in the cylinder, so that when the forked passage communicates with the port of the cylinder the inflamed charge of the former will readily enter and ignite the charge of the latter. The action will be better understood by reference to fig. 186, where the slide has formed in it the chamber B, and it has also an opening in the inner face of the slide which communicates with the small passage K in the cylinder above the inlet port, the passage having a lateral notch, and

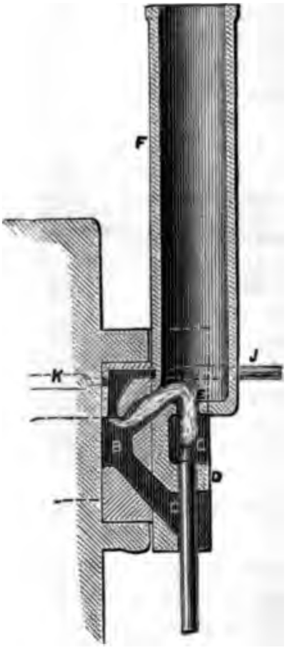

Fig. 186.—Arrangement for igniting the charge in Otto's Gas Engine, 1877.

being arranged in such a position relatively to the chamber B that it establishes a communication between the chamber B and the interior of the cylinder through the passage K, just before B communicates directly with the inlet port. The slide being in the position shown in fig. 186, air enters B through C, and gas enters it through H, and the mixed charge is ignited through the hole E by the flame G. Charles Linford patented 1,470, 'Improvements connected with gas engines,' in which two cylinders and two single-acting pistons are connected so as to operate as a double-acting engine. The eduction valve leads to a receiver in which a vacuum is maintained by an air-pump or otherwise to start the engine. The details of the engine are of a competent engineering character, and some of the most essential of them are shown in fig. 187, where A is the water-jacket for a cylinder B, in which works a piston C in a downward direction under the force of the explosion of a mixture of gas and air. The explosion takes place in the upper part of the cylinder only, the opposite end of the cylinder being open to permit the atmospheric pressure to return the piston. The cylinder B has a narrowed extension *j*, of cylindrical or other form, in which is fitted a ring K. It is pierced with holes for the passage of the gas into the chamber *j*, where the gas commingles with the air previously let in by the valve prior to the charge being exploded by an outside flame in the usual manner; *m* is the air inlet passage, and *n* the gas inlet; *p* is the exhaust passage in the extension *j*, the outlet from which to the pipe R is governed by the valve Q. F. S. Barff, professor of chemistry obtained a patent (No. 1,682) for 'Improvements in obtaining motive power.' These improvements consist in the use of carbonic oxide and hydrogen for the generation of power. The gases are got by sending a stream of steam through a retort like an ordinary gas retort filled with coal, and heated to a high temperature.

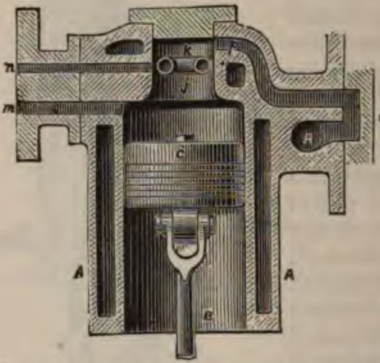

Fig. 187.—Linford's Gas Engine, 1877. Section through Cylinder.

F. W. and W. J. Crossley, well known as the makers of the Otto engine, patented 2,177, 'Improvements in gas motor engines,' consisting of arrangements for reducing the necessary pressure of the spring keeping the valve up to the face, by making the valve partly on the equilibrium principle; also abandoning the stratified arrangement of air and gas mixture, and using a uniformly diluted combustible charge. In order to obtain a sufficiently rapid ignition a special chamber is provided, communicating with the cylinder and lighting flame, into which is introduced an undiluted charge of the explosive mixture. On ignition of this strong charge the resulting flame will be projected with force into the cylinder, and being thus brought into extended contact with the diluted charge will effect its rapid combustion, and produce the maximum pressure before the piston has travelled far. The tapered end of the cylinder is given up, and a long, narrow continuation of the inlet port is carried well into the cylinder. James Robson patented 2,334, 'Improvements in engines operated by the combustion of gas or vapour.' One arrangement described has a cylinder closed at both ends. The piston is used to draw in a charge of gas or vapour and air at one side, which is forced into a reservoir, and retained there until the piston returns to the back end of the cylinder. The gas is next inflamed by being brought into contact with a flame, and the piston is driven forward by the force of the explosion generating power. A second arrangement consists in the propulsion of a loose piston by the explosion producing a vacuum, and the power is generated by the return of the air into the void thus produced. This is the principle of Brown's vacuum engine, and of Otto's original form of gas engine, and there was no novelty at this date in such an application. This concludes the review of 1877.

Q. What have you to describe for 1878?

A. There is not very much for that year. First we have the patent No. 633, granted to A. N. Porteous for 'Improvements in the production of hot-air gas, and in the use of the same for motive purposes and for illumination.' The production of gas is obtained from liquid hydrocarbons. The invention consists in forcing air by means of a pump or blower into a tank so as to obtain the required pressure therein, then passing air therefrom under pressure through a furnace, such heated air being then passed through a chamber containing a sponge or other suitable material saturated with paraffine or other suitable hydrocarbon. This design secured provisional protection only. There is next the patent No. 942, granted to Charles Linford. In this design the cylinder contains a second piston behind the working piston, which second piston is used for charging the cylinder. The second piston moves towards the working piston, and expels the products of combustion on one side, while on the other side it draws in a combustible charge. The eduction valve is then closed and the second piston returns, and the charge is caused to pass through the body of the second piston to the exhaust side of the working piston, where it is compressed. And when the working piston has completed its inward stroke the charge is fired, during which time the second piston remains stationary. For firing the charge the valve is of the ordinary mushroom or flat-face type. But connected to its stalk is a lever attached to any convenient part of the engine, so as to lift the valve at the right time to fire the charge, a light being kept burning below the valve, which is brought into direct communication with the charge in the cylinder. Fig. 188 is a plan of a combined mixing and lighting valve. Fig. 189 is a longitudinal section of the lighting valve, and fig. 190 is a sectional elevation of fig. 188 at the line *o o* in fig. 189. *a* is an air port, *b* a mixing chamber, *c* a port to the cylinder, with a small gas passage; and there is also a larger passage for gas. *j* is a chamber for the supply of gas during the motion of the valve *g*; *h* is a gas supply pipe. There is a small pipe with cavity *n*, 1 an inlet pipe, and 2 an outlet pipe to the valve *g* by the passage shown by dotted lines in fig. 190. The valve is worked by an ordinary governor, the valve *g* being moved in its case by the lever *g′*. H is a lighting valve, worked in the case Z′ by the lever H′; *o* is a chimney for carrying off the heat from the combustion of the gas in the chamber *b*; *d* is a gas supply pipe to the chamber *a* by the passage *e*; *c* is a pipe connecting the

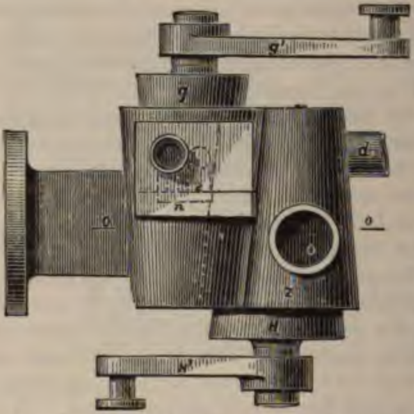

Fig. 188.—Plan of Combined Mixing and Lighting Valve. Linford, 1878.

chambers *a* and *b* in the chamber *b*. The gas is ignited by the outside light as shown in fig. 190; *r r* are air ports to assist the combustion of the gas in *b*; *r* is the escape port to the pipe *o*. The dotted lines r^1, r^2, r^3 show the position of the ports when the valve H is brought into position for firing the charge in the cylinder by the port *c*; *e*, fig. 189, is a small passage for the admission of a portion of the compressed charge in the cylinder into the chamber *a* slightly before the port r^1, fig. 190, opens to the port C to equalise the pressure in the chamber *a* when the ports *r r r* are closed. In the patent No. 3,045, granted to Dugald Clerk for 'Improvements in gas motor engines,' the power is developed in one acting cylinder having combined with it a compressing pump. The air and gas are admitted to the pump by means of a valve which is in the form of a plate, and slides between a port face and cover. The air and gas pass into the pump when its piston moves outward, and become mixed therein, and on the return of the piston the mixture passes through a lift valve into an intermediate reservoir. In 1879 another patent, No. 2,424, was taken out by the same inventor for 'Improvements in gas motor engines,' which profess to be

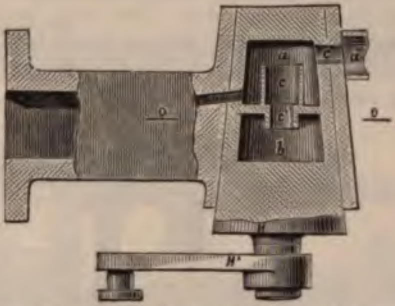

Fig. 189.—Section of Combined Mixing and Lighting Valve. Linford, 1878.

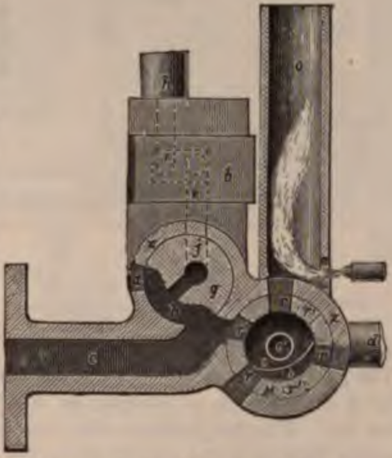

Fig. 190.—Sectional Elevation of Fig. 188. Linford, 1878.

emendations on the foregoing. But the deviations are immaterial, and are not marked by much originality. The use of asbestos is suggested, as had often previously been done. In No. 4,843, William Foulis of Glasgow patented 'Improvements in gas and hydrocarbon engines.' The main peculiarity of his engine is a method of lighting the gas shown in fig. 191. Gas enters by the pipe *k*, and compressed air by the pipe *l* (which may be supplied by a small pump worked by the engine) to the surrounding pipe *m*.

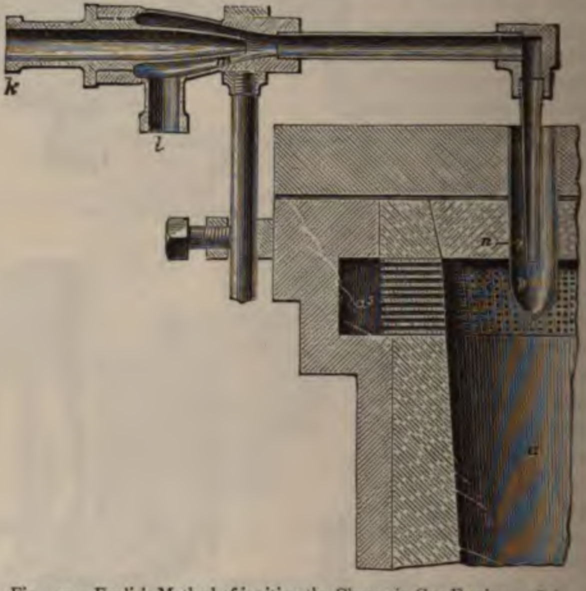

Fig. 191.—Foulis's Method of igniting the Charge in Gas Engines, 1878.

The gas and air proceed together to the jet *n*, which is surrounded by a chamber, *p*, of platinum or other suitable material, open at the top. The gas jet heats this chamber sufficiently to ignite the acting charges of gas and air within the cylinder, and when the temperature of the combustion chamber is raised sufficiently to ignite the charges of gas and air, the jets may be turned off. In the patent 5,092, granted to R. Hallewell for 'Improvements in gas motor engines,' reference is made to a former patent taken out by the same inventor in 1876, and of which the present may be regarded as an amplification. The end of the cylinder is extended to form an explosion chamber. The explosion takes place at every alternate stroke. During the intermediate strokes the piston draws in and compresses air, and the gas pump forces the gas in against this

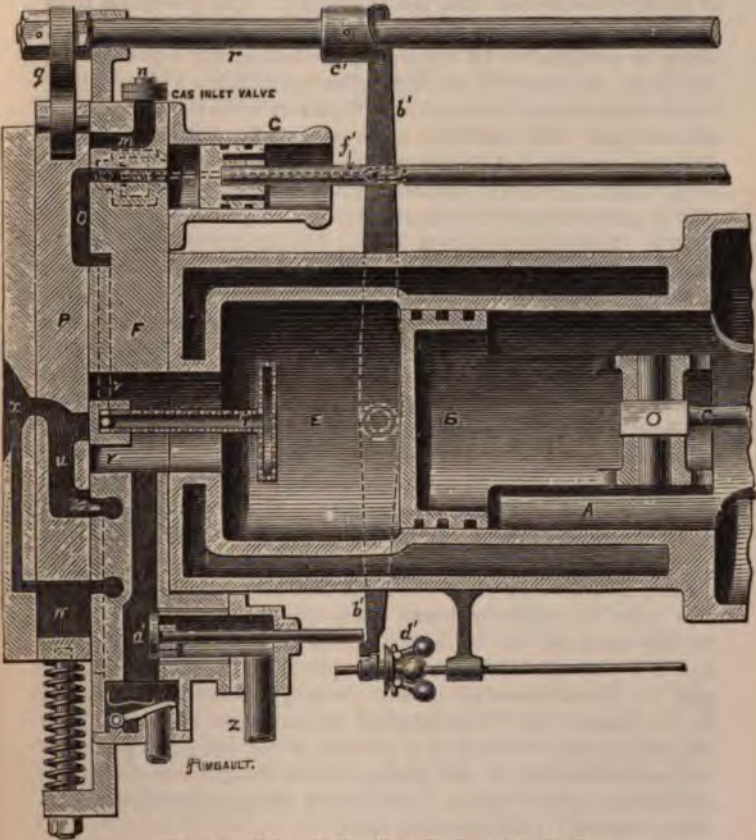

Fig. 192.—Hallewell's Gas Motor Engine, 1878. Section.

high-pressure air through minute perforations. In fig. 192 a vertical section of part of the engine is given. A is a cylinder in which works a piston B. At the upper end of the cylinder is an explosion chamber E, which is formed by extending the upper end of the cylinder. Upon the top of this extension is secured a head F, in which are formed gas and air passages, and in and upon which the slide valve works. To the under side of the head is secured a gas pump G. In the head F are formed two gas ports m m ; and one of them is connected with the gas supply. The gas passes from the said supply pipe to the port m through a self-closing valve, which is arranged to be opened by the exhausting action of the gas pump. A cavity o in the slide valve P establishes a communication between the ports m and m at the times when the pump has to draw in gas. The said slide valve is provided with a roller upon which acts a cam q, which is fixed upon a shaft r. At the beginning of the stroke the cavity o establishes a communication between the port m and a hollow perforated body T through a passage in the head F. In the slide valve is formed a firing chamber v. In the head F are two ports v v, which open into the explosion chamber. A cavity w serves to maintain a communication between a passage leading to the gas jet x and a gas supply passage. In the head F is formed an air inlet passage Z, which is provided with a self-closing valve which opens inwardly. The said head is also formed with an exhaust passage, which is fitted with a valve a^1, which is provided with a spindle upon which a spring acts to close the said valve. A lever b^1 is mounted upon a fulcrum, and is acted upon by a cam c^1, which is fixed upon the shaft r. The lever b^1 is also arranged to be acted upon by the sleeve of a governor a^1, which receives motion from the crank shaft. If the engine exceeds its normal speed the sleeve of the governor raises the lever b^1, thereby opening the valve a^1. It at the same time acts upon the spindle f^1 of a valve, indicated by dotted lines, opening the said valve, and thereby admitting air to the gas-pump. C is the connecting rod, and O a passage leading from the gas pump to the distributing pipe T. There is next the patent No. 5,133, granted to F. W. and W. J. Crossley for 'Improvements in gas motor engines,' which consists mainly in storing up a portion of the hot gases produced by the combustion of the charge, and utilising them during the next stroke of the engine, somewhat on the principle of the compound engine. This completes 1878.

Q. Against the time at which we have now arrived, many of the patented devices must have ceased to be patentable from having been specified by previous inventors whose patents had expired, or who had not pursued them beyond the provisional stage?

A. That no doubt is the case ; and the remark applies with still more force to the patents of later inventors. Every year we find many expedients patented which had been patented long before, and the period of protection for which had run out, so that they had become public property. Among these common or optional devices are, lighting by electricity; lighting by a subsidiary explosion; lighting by the interposition of platinum, which becomes hot by a jet of cold inflammable gas playing upon it, and eventually lights the jet; lighting by the application of external heat; and many other variations in the mode of lighting. Then for getting rid of the products of combustion within the cylinder we have the same methods patented again and again. Among them we have the application of a vacuum cylinder to suck the products away, the application of a compression plunger to force them out, blowing-through the cylinder by air or steam, and the use of a subsidiary explosion to blast them out. Some inventors claim it as a merit to use a high pressure of air, as if the effect of that was not plain, and the alternative obvious to everyone. Air, whatever its pressure may be, doubles its volume by being heated about 500° Fahr., and there is clearly more power to be got by doubling the volume of a pound of air of 100lbs. pressure than of a pound of air of 15lbs. pressure. Dissociation, and the imperfect combustion of the gas, which are the really important points, do not seem to have been taken into account.

Q. What was there in 1879?

A. First we have the patent No. 2, granted to H. Williams and J. Barron for 'Improvements in and relating to atmospheric and gas motor engines.' The invention consists in the introduction of compressed air into the cylinder; and upon the piston reaching the most advantageous part of the stroke, a charge of inflammable gas is then forced into the air within the cylinder at a point in proximity to a kindling flame. By this arrangement it is said the sudden explosions are obviated, such as occur in other gas engines, while a maximum power is got from a minimum of gas. There is next the patent (No. 1,450) granted to Richard Hallewell for utilising the hot gas in the manner previously proposed by Crossley. In the patent (No. 1,500) granted to C. Linford various modifications of detail are propounded with little novelty. The gas is fired by electricity. Reference has been already made to Rider's hot-air engine, in which two vertical plungers are used, connected transversely by a short lever, and in which the air is heated by an external fire. In 1879 a patent (No. 2,191) was granted to Martin Benson on behalf of Rider for an adaptation of this species of engine, of such a character that the air should be heated internally by the combustion of gas, or of the vapour of some fluid hydrocarbon. In this engine the igniter is an oil lamp, which is relighted at every stroke by a permanent flame. The following are the advantages and novelties claimed, but a large deduction must be made from these pretensions in forming a sound estimate of their value :—1. In a gas engine the construction or combination of a compression and a power cylinder with appropriate parts, so arranged that any desired degree of compression may be applied to the mixed air and gas without the necessity of using a reservoir or an inlet valve for the motive cylinder. This arrangement also provides for positive power in the engine at each revolution, thereby simplifying the machine, and giving greater power as compared with the size of the engine. 2. Separate compression of gas and air in proper proportions, and mixing them after compression, whereby all risk of explosion is avoided. 3. An arrangement by which the desired proportional and exact quantity of gas is used in each charge of air, thereby insuring maximum economy of gas. 4. Compression of the air, and also of the gas in cool cylinders, and igniting the mixed gas and air in a cylinder of considerably elevated temperature, thereby utilising the greatest amount of power, and avoiding the necessity of water-jacketing the motive cylinder, which has also the effect of reducing the amount of power absorbed in compression to a minimum. 5. The perfect regulation of speed by causing the gas supply pump to become inoperative when the speed is too high. 6. The use of leather packings, thereby lessening the cost of construction, and making the machines more perfect with greater facility. 7. A novel construction of the igniter, by which it is much easier made, and is more perfect, durable, and reliable, and also requires less power to operate it. 8. The employment of effective means (by blowing through at each stroke) to wash out the carbonic acid or burnt air from the hot or motive cylinder at each revolution, thereby ensuring more perfect combustion. 9. The ready adjustment of all important operative parts, by which the amount of compression, the quantity of air used at each revolution, the proportional quantity of gas, and time of ignition may be varied at pleasure with great facility. 10. The adaptation of the generator surface to gas engines, whereby much of the waste heat is utilised. 11. The peculiar construction of the gas-pump, by which only a portion of its stroke is effective. thereby causing the gas to be delivered into the engine at the proper time and in exact prearranged quantity. Dugald Clerk obtained a patent (No. 2,424) for 'Improvements in gas motor engines.' It refers to the previous patent No. 3,045 of 1878, and describes some immaterial modifications thereupon. The igniting arrangements are very similar to Crossley's. No. 3,213 is a patent granted to James Atkinson for 'Improvements in gas and similar engines.' He employs two single-acting cylinders placed side by side. The plunger of the compressing cylinder, in making an outward stroke, draws in a charge of air or air and gas, and during the return stroke this is compressed and delivered into a chamber, which by preference is of such a capacity as will just contain the charge at the desired pressure. The charge is then admitted into the working cylinder, and is there ignited. The working cylinder is lined with terra cotta or some other refractory material. The charge may be ignited by a thin piece of platinum or porcelain, heated in one spot by a jet on the outside, or it may be fixed in a slide and travel with it. Picking and Hopkins obtained a patent (No. 3,561) for a gas engine, but there is no feature of novelty in it. Wittig and Hees obtained a patent (No. 3,732) for 'Improvements in gas and petroleum engines,' in which arrangements are specified for compressing a mixture of gas and air, and then firing it in a cylinder so as to generate power, after the fashion already done by many other persons. Hugh Williams, in a patent (No. 4,340) taken out by him, refers to a former patent (No. 2 of 1879) and describes some improvements in details thereupon. The air and gas valves are made mushroom valves, and the kindling valve is a hollow cylindrical valve with a light inside. The charge of gas within the valve is ignited by a master-light. The drawings of the engine given are very similar to those of the Otto engine. C. W. King and A. Cliff obtained a patent (No. 4,337) for 'Improvements in obtaining motive power, and in the apparatus employed therein.' This engine is partly a gas engine and partly the adaptation of Stirling's regenerative arrangement. The engine consists of a receiver, which contains a displacing plunger, not necessarily close-fitting, but resembling Parkinson's. One end of the receiver is kept cool by the circulation of water in tubes, and the other end is maintained hot by the explosion or combustion of charges of combustible fluid and air, introduced therein by a compressing pump. An igniting arrangement is placed in the hot end of the receiver, consisting of a platinum cup with a blow-pipe flame directed upon it from the outside. The main cylinder is in constant communication with the cool end of the receiver. In this cylinder the whole contained fluid of the engine expands and is compressed during the forward and return strokes of the plunger working therein. A portion of the contained fluid is allowed to escape into a cylinder, in which it expands, being afterwards ejected into the atmosphere. This concludes 1879, so far as space permits.

Q. Will you now describe the patents for gas engines taken out in 1880?

A. The first is No. 117, granted to H. Robinson for 'Improvements in gas motor engines.' In the patent No. 2,344, granted to the same person, similar improvements are described, but in neither case is there anything new or requiring special notice. Edmund Edwards, in No. 760, patented 'Improvements in motive power engines.' He forms a vertical engine with a trunk piston or plunger, and at or near the centre of the height makes a port, through which an explosive mixture of air and gas is admitted. Below the admission port a small flame is kept burning, and a corresponding small opening is made laterally into a vertical passage formed in the plunger. The explosion forces up the piston to the end of the stroke, and the residual gases escape into the atmosphere. W. Foulis patented No. 2,442, which provides for the use of a hot piston of refractory material, and a mode of expelling foul gases. The arrangements prescribed by this inventor are uniformly able and judicious. In No. 4,075, granted to S. Clayton, there is nothing new, and several patents are here omitted which have nothing new in them. From this judgment must be exempted the patent No. 3,685, granted to Williams in this year, but which, having been subsequently produced in an improved form, need not be further referred to at this stage. No. 4,270 of 1880 is a patent granted to Charles Gruntley Beechey for 'Improvements in gas motor engines,' in which the novelties claimed are—1st, closing the exhaust valve before the end of the stroke, so that, as a greater or less amount of exhaust products remains in the explosion chamber, a greater or less amount of explosive mixture is admitted thereto; 2nd, the employment of means for regulating the amount of air and gas drawn into the compression pump; 3rd, providing a space in the piston into which the mixture of air and gas is compressed; 4th, the employment of stationary exploding burners which are supplied with gas and air of a high pressure; and, 5th, the means for supplying these burners with a high pressure of air and gas. The object of the high pressure is to prevent the gas from being extinguished by being blown out before the explosion takes place.

The explosion extinguishes the jet, but it is relighted by a master-jet. The burner may either be stationary or carried by the slide valve. The details seem judicious, but there is no novelty in them. No. 4,297 of 1880 is a patent granted to F. W. Crossley for 'Improvements in gas motor engines.' The main improvement consists in providing a pump worked by the engine, which, when the products of combustion are let out, will blow through the engine to expel them completely. There is nothing new in this provision. Steam would do better. A. K. Rider, No. 4,419 patents 'Improvements in gas engines.' The general structure of this engine resembles that of Rider's hot air engine, already referred to. The plungers are packed with leather, and a gas pump is placed beneath the air-compressing plunger. The igniting mechanism consists of a platinum tube ⅛ inch diameter, and 1¾ inches long. For half an inch at one end it is perforated with numerous holes, and around and over this perforated portion is wound a fine platinum wire. This tube is encased in a larger tube of about ¼ inch diameter, and 1½ inches long, one end of which is shut up and closed by a cap. A current of air and gas can flow through the inner tube through the fine perforations at its end and the coil, where an intense combustion occurs—the products of combustion returning between the inner and outer tubes to the open end of the larger tube where the burnt air escapes. The igniter is supplied with a mixture of air and gas by a small pump. The igniter is fitted into a chambered tube in the side of the power cylinder some distance from the bottom, so that it is covered by the piston until the right time for explosion occurs, when the exposure of the igniter in an incandescent state explodes the charge. No 4,881 is a patent granted to L. Simon for 'Improvements in gas motor engines.' The chief novelties claimed are—1st, placing an exhaust port on the cylinder in such a position as to permit a part of the products of combustion to escape by virtue of their own tension before the end of the stroke; and, 2nd, igniting the charge by means of a travelling flame carried in a piston valve to a chamber, where a preliminary explosion is thus produced. No. 5,101 is a patent granted to W. E. Richardson for 'Improvements in gas engines,' proposing to carburize air or gas by petroleum for the production of power. This patent was not proceeded with. This terminates the patents of 1880.

Q. Will you now describe those taken out in 1881?

A. The first is No. 60—'Improvements in gas motor engines'—

granted to N. A. Otto. To expel the products of combustion from the space provided for the explosion of the charge at the end of the cylinder, an auxiliary piston is employed, or the stroke is made capable of having varying lengths. There is not much in this patent that is either new or expedient. No. 180 is a patent granted to W. Foulis for 'Improvements in gas engines.' It contains many ingenious arrangements, and is well worthy of careful study. The claims are as follows:—1. The general arrangement and combination of parts constituting the gas engine. 2. In gas engines the combination of a pump and a power cylinder, consisting of a combustion chamber, which becomes highly heated, and a working cylinder, which is kept comparatively cool, and which is of larger capacity than the pump, wherein the stroke of the pump is made to the rear of the stroke of the piston of the cylinder, to such an extent, in accordance with the relative capacities of the pump and working cylinder, that the mixture of gas and air, when it passes into the lower cylinder, is expanded during its passage thereinto at a pressure equal or about equal to that in the pump. 3. In gas engines the means for igniting the gas and air in the power cylinder, consisting in the combination of an igniter and passage with an intermittent jet in communication with the pump which supplies air and gas to the working cylinder. 4. The use in gas engines of a knob, or piece of fireclay, or asbestos, or like material, in combination with an igniter, whereby the said knob is heated during the first period of the engine's work, and thus itself forms the means of igniting the gaseous mixture during the subsequent action of the engine. 5. In gas engines, the combination with and use in the entrance pipe for the gaseous mixture of wire gauze, and an annular space or orifice, through which the entering gaseous mixture passes at a velocity sufficient to prevent back-firing, together with means for preventing the overheating of the said parts. 6. The combination with the arrangement claimed in the 5th clause of a passage in front of the said contracted space or orifice. 7. The combination in gas engines of a regenerator between the wire gauze and contracted space claimed in the 5th clause, for causing the heat of the burnt gases to be taken up by the entering gases. 8. The employment in the passages between the pump and power cylinder of one valve with different areas for opening at the requisite pressure. 9. The arrangement for governing the quantity of explosive mixture admitted to the engine. 10. In the power cylinders of gas engines, the groove or recessed part between the two portions of the power cylinder. 11. A valve for admitting the required regulated quantities of air and gas to the pump and to the igniter heating jet, and for passages adjusting the proportions thereof, so that when adjusted the passages may be regulated to admit the air and gas. 12. The use in combination with gas engines of apparatus for supplying gas and air to the igniter heating jet. 13. The combination of an inner casing or chamber at the back end of the power cylinder with means for causing a current of air to pass thereinto during the latter part of the forward stroke of the pump piston. 14. The combination with gas engines of means for starting the engine by a series of explosions or ignitions of the gaseous mixture after the full charge has entered the said combustion part of the cylinder. 15. Placing the igniter in such a position that it at once ignites the mixture. No. 320 is a patent granted to C. M. Sombart for 'Improvements in gas engines,' and these improvements consist wholly of emendations in the details of Bisschop's gas engine. In the patent (No. 565) granted to A. T. Allcock for 'Improvements in gas engines,' the engine resembles very much a common steam engine. A cut-off valve is employed, which determines the admission of the combustible mixture and also the point of ignition. No. 596 is a patent granted to P. Giffard for 'Improvements in dilated air motive power engines.' A fire for heating the air is set under the cylinder, and is surrounded by a coil of air-heating pipes. The piston ring is made of leather or india-rubber, as it is so far removed from the fire that the heat is not great at that point. F. H. Wenham patented 'Improvements in combined gas and heated air engines' (No. 867). The air is heated by gas to produce motive power, the mixture of gas and air being lighted by a permanent flame acting on a touch-hole; and although the permanent flame is blown out at every stroke, it is re-lighted by a cage of platinum wire placed in the permanent flame. No. 1,078 is a patent granted to H. C. Fleeming Jenkin and A. C. Jameson for 'improvements in caloric motor engines burning solid fuel. The object of this invention is the construction of a caloric motor engine, which, while essentially an engine of the Stirling type, differs from the Stirling engine in using instead of air the products of combustion of solid fuel burnt in a grate directly connected with the interior of what Stirling calls the air vessel, and here called the displacer chamber, so that the products of combustion are discharged from the grate into the displacer chamber partly by expansion under the influence of heat and partly by flow, the pressure in the grate chamber bearing always such a relation to that in the displacer chamber that the products of combustion are not driven so far back into the grate as to impede combustion. A long and elaborate specification is given, and arrangements are described of so elaborate and transcendental a character as to be quite impracticable. No mode of feeding solid fuel into a furnace with much internal pressure has yet been contrived, and the arrangement here prescribed is very crude. We now come to the patent (No. 1,089) granted to Dugald Clerk for 'Improvements in motors worked by combustible gas or vapour.' The engine is of the horizontal kind, with a compression pump and lighting arrangement very similar to Otto's and Crossley's. Fig. 193 is a horizontal section of this engine. A single-acting cylinder, 11, is fixed horizontally in a jacket casing, 12, formed at one end of a bed frame, 13. The piston, 15, is in the form of a hollow plunger or ram, but is fitted with a number of metallic packing rings. 23 is the piston of the displacement cylinder, 24, which is placed horizontally at one side of the power-cylinder jacket, 12, being formed in a casting, 25, which is bolted to the jacket, 12. At the inner end of the power-cylinder, 11, there is a conical clearance space, 26, formed in the casting, 25, as is also the jacket space, 27, which communicates with the space in the jacket, 12. Both of these are filled with water to prevent the power cylinder, 11, and the clearance space, 26, from becoming overheated. The air and gas enter the power cylinder, 11, by an inlet, 30, at the outer end of the conical clearance space, 26, and the exhaust takes place through ports, 31, communicating with a passage, 32, formed round the cylinder, the ports, 31, being uncovered by the piston, 15, as it approaches the outer end of its stroke. A pipe, 34, forms a communication between the exhaust pipe and a part of the cylinder, 11, nearer the inner end, so as to facilitate the starting of the motor by the opening of a stop-cock. A pipe, 39, connects the displacement cylinder, 24, with a valve box, through which, by the action of the piston, 23, air and gas is forced into the cylinder, 11. 44 is a vertical passage by which the gas has access to a check-valve. The slide-valve, 45, is fitted to work horizontally across the back end of the casting, 25, a recess being formed for it, and having a vertical port-face piece fixed at its innermost part. It is kept in position by an adjustable covering plate, 46, which is pressed against the slide by a bar, 47, acted on by adjustable

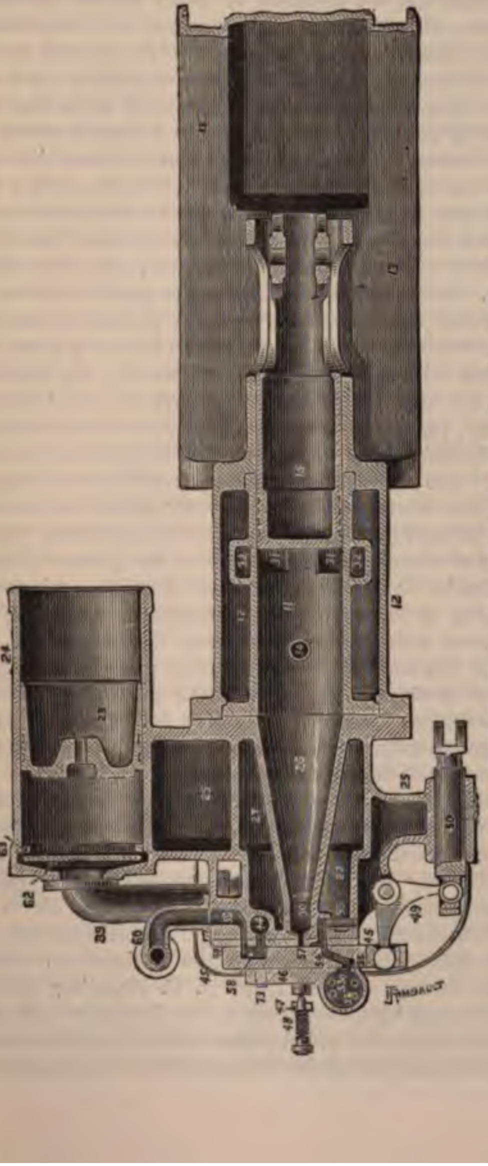

Fig. 193.—Clerk's Gas Engine, 1881. Horizontal Section through Cylinder and Pump.

helical springs, 48, on spindles or studs passing through the covering plate, 46, and fixed in the casting, 25. The valve slide, 45, is directly acted on by a bell-crank lever, 49, itself moved by a bar, 50, working in guides. The covering plate, 46, is formed with a small open-topped chamber, 52, in which a jet from a small gaspipe, 53 (by preference arranged like a Bunsen burner), is kept constantly burning. This chamber has at its inner side a port, past which the slide valve, 45, moves. The slide, 45, has a main passage or space, 54, formed in it and extending partly along it, and this main passage, 54, has a port on each side. A very small passage communicates through a grating, 55, with the main passage, 54. When the slide, 45, is in the position shown in the figure, the outer port of its main passage, 54, is in communication with the port of the chamber, 52, in the covering plate, 46, and then the gas which has entered the passage, 54, through the grating, 55, becomes ignited. At this time the inner part of the main passage, 54, of the slide communicates with a passage, 56, leading to the outside, which insures the filling of the passage, 54, with flame. The immediately subsequent movement of the slide, 45, cuts off the communication of the outer port of the passage, 54, and brings its inner port into communication with a port, 57, leading into the end of the clearance space, 26, of the power cylinder, 11, and the flame in the main passage, 54, of the slide, 45, is thereupon communicated to the combustible mixture in the space, 26, all communication with the exterior being completely cut off. A cavity, 58, of the slide, 45, puts a port of the passage, 44, at the proper time in communication with the port of a passage, 59, which leads the gas from the supply-pipe, 60. The slide valve, 45, allows the gas to enter mixed with air during the early part of the indrawing stroke of the displacement piston, 23, but cuts it off at a suitable part of the stroke, so that only air enters during the remainder of the stroke; and in order to prevent as much as possible the air last drawn in from mixing with the combustible mixture previously drawn in, there is placed in the end of the cylinder, 24, a plate, 62, which causes the entering air to spread from the centre to the circumference, and thence enter the cylinder between the plate, 62, and a ring, 63, and in directions converging towards the centre. In No. 1,130 H. C. Fleeming Jenkin and A. Jameson patent 'Improvements in caloric motor engines, using gas as fuel,' having no doubt found that their solid fuel scheme would not work. A long description is given of a complex and bulky arrangement, necessarily costly and much less eligible than that of any of the ordinary gas engines in common use. In the patent 1,202, for 'Improvements in caloric engines, wherein the working fluid is heated by the internal combustion of gas or other fuel,' M. P. W. Boulton states that, if the pressure be greater inside the cylinder than outside, a supplementary ignition valve must first be opened to equalise pressure in the ignition passage and main ignition valve. In the patent (No. 1,388) granted to A. Ewens and H. Newman for 'Certain Improvements in gas engines,' the engine described is of a simple character, but there is nothing unusual in its design. In No. 1,723, W. Watson patents an improved method of exploding gases used in gas engines. This is to be done by applying a blow-pipe flame to the outside of a projecting nipple or thimble, which within is in contact with the gas that has to be ignited. No. 1,765 is a patent granted to E. Edwards for 'Improvements in motive power engines.' It refers to the patent No. 760 of 1880 taken out by the same person. He admits the air and gas to the engine through pipes perforated with small holes to improve intermixture, and he prefers to ignite the combustible mixture by means of a rotating valve with corresponding holes and an igniting flame outside. James Robson (No. 2,083) took out a patent for 'Improvements in motive power engines,' in which he describes various details or alternative methods, but without any material novelty. A. Clark obtained a patent (No. 2,408) for a combined gas engine and pump; but there is nothing in it of any importance. Sir C. W. Siemens obtained a patent (No. 2,504) for 'Improvements in gas motors and producers,' which show a considerable advance upon his patent of 1860, but are still too complex to justify any expectation that they will come into use. C. W. Pinkney took out a patent (No. 2,645) for 'Improvements in gas engines.' The main improvement is the combination with a hollow reciprocating igniting plunger of a screw valve for regulating the passage of the compressed explosive compound. No. 3,330 is a patent granted to M. V. Schiltz for improvements in gas, hydrocarbon, and other motive power engines. The following are the advantages said to be attained:—1st, the suddenness and force of the explosion is converted into an equable power; 2nd, the heat generated is fully utilised for producing power; 3rd, the application of petroleum and other hydrocarbons is facilitated. The first object is attained by using several successive explosions in each stroke, the second by injecting water behind the piston. On the whole, this is both a very elaborate and a very judicious patent, but it is somewhat wanting in simplicity. No. 3,367 is a patent granted to M. P. W. Boulton for 'Improvements in engines wherein a piston is propelled in a cylinder by ignition of inflammable gas or fluid.' It contains various suggestions, the most important of which have been anticipated by other inventors. No. 3,715 is a patent granted to H. Williams for 'Improvements in gas engines, and the automatic generation of gas therefor.' He generates gas from petroleum by heating it in a retort by means of a lamp, which may be that of the master-flame or any other. He prefers the retort to be of platinum. Before being heated, the petroleum should be mixed with water or steam, else the crust that will form on the retort will soon disable it. No. 4,137 is a patent granted to R. Watson for 'Improvements in obtaining motive power by means of combustible gas or vapour,' in which he proposes to make the combustion continuous. There is nothing new in the provisions of this patent. No. 4,244 is a patent granted to J. Spiel for 'Improvements in motor engines worked by combustible gases or vapours and steam.' The specification is an elaborate and wordy one, but there is nothing novel or useful in it. No. 4,340 is a patent granted to C. T. Wordsworth and others for preventing the lighting jet from being blown out by introducing a pressure of air to it at opposite sides, so that there is no more tendency to blow it in one direction than in another. Details of lighting are alone given. No. 4,402 is a patent granted to G. W. Weatherhogg for 'Improvements in single and double-acting compound air and gas motor engines.' The compression and expansion of the combustible charges of gas or vapour are effected in a compound cylinder, and two combustible charges are fired and expanded during the same stroke, the same cylinder being also available for compressing atmospheric air and other fluids into a superheater for regenerating the heat of the waste gases. No. 5,056 is a patent granted to A. E. and H. Robinson for 'Improvements in hot air engines.' This is an ably designed and carefully described invention, but resulting in an apparatus too complex for popular use. No. 5,178 is a patent granted to J. Shaw for 'Improvements in gas motor engines.' The chief improvement suggested is the erection of a closed vertical pipe at the back end of a horizontal gas engine, and rising above the level of the cylinder. Into this pipe the air and gas, it is expected, will ascend from pipes beneath, and will be thus in a great measure isolated from the products of combustion. No. 5,201 is a patent granted to W. W. Tonkin for 'improvements in motive power engines.' An elaborate specification, but nothing new in it. No. 5,350 is a patent granted to Sir C. W. Siemens for 'Improvements in engines worked by the combustion of gaseous fuel.' But it is very little more than a repetition of the patent previously granted to the same person in the same year. This concludes the patents of 1881.

Q. Will you now proceed to describe the patents of 1882?

A. No. 7 of 1882 is the patent granted to S. Sudheim for 'Improvements in double-acting hot air engines,' in which some modification is described of the displacer piston; and details of other parts are given. This engine is not an explosive engine, but is heated externally. The cylinder is formed with a pot-bottom to which the heat is applied. But there is ample experience to show that such heating-bottoms are soon worn out. No. 362 of 1882 is the patent granted to F. W. Turner for 'Improvements in gas engines.' There are two cylinders, the pistons of which are coupled to separate cranks on the same shaft. The cranks are at right angles with one another. The gaseous charge is ignited in the first cylinder, and during the outward movement of the pistons it exerts its expansive force in both cylinders, which are then placed in communication by an intermediate port or passage. As shown in fig. 194, the piston B, having performed nearly half its downward stroke, and the piston B′ being at the top of its stroke, the cylinder A, above the piston B, contains gas and air, which have been admitted by the opening of the valves G and P. The valve G is about to rise for the further admission of gas from the supply aperture *i*, through the port K. The valve F is also about to be opened by means of a cam. When the piston B has reached the end of its downward stroke, the cylinder A is filled, and the cylinder A′ is half-filled with the charge of gas and air, when the supply is cut off. During the upstroke of the piston B the whole of the charge is compressed into the cylinder A′. By the further movement of the engine in the same direction the charge is compressed from the cylinder A′ into the cylinder A, and the piston B again arrives at the position shown in the drawing, the revolution of the crankshaft having been completed. By this time, the valve G has moved downward to allow the charge to be ignited, and the valve F being open, the total force of the explosion is exerted simultaneously upon the two pistons. C C D K are parts of crank shaft; G valve

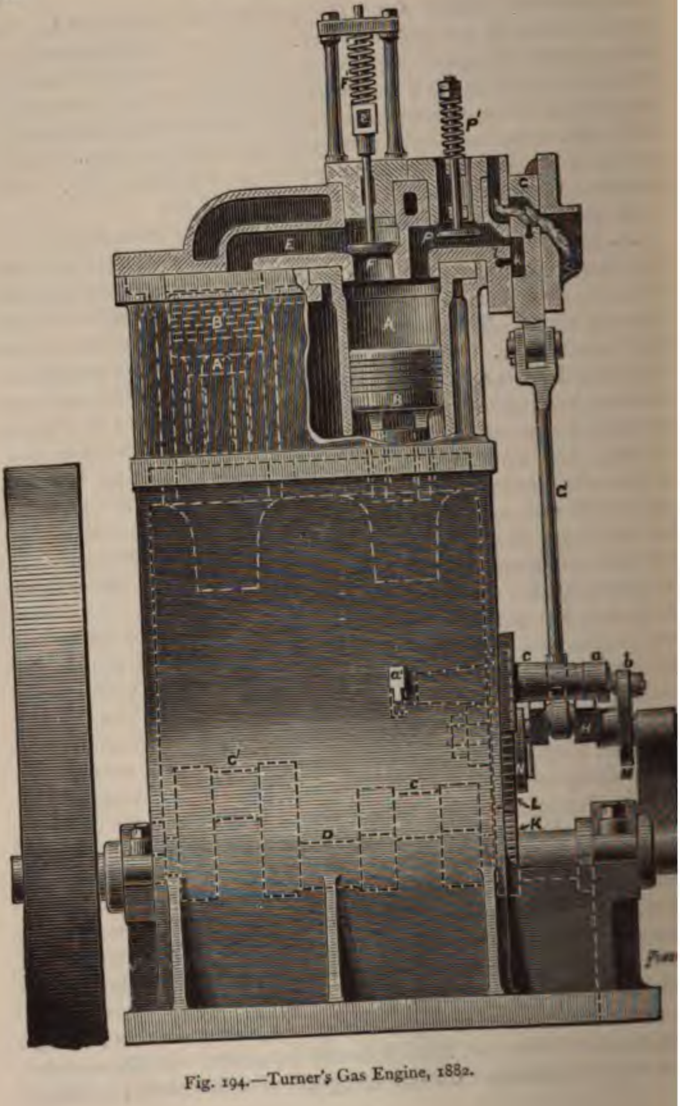

Fig. 194.—Turner's Gas Engine, 1882.

rod; and HIJKLMN and *a a′ b c* parts of valve gear. No. 397 of 1882 is the patent granted to C. Emmet for 'Improvements in gas engines.' The general arrangement is similar to that of the best gas engines, and all the parts of the design are very complete and judicious. The gas pump can be disconnected and worked by hand, so that the engine can be started without turning the fly-wheel. No. 417 of 1882 is the patent granted to S. Withers for 'Improvements in gas engines.' A cheap and simple form of engine is described, but there is no novelty in it. No. 579 of 1882 is the patent granted to A. de Bisschop for 'Improvements in gas engines.' These improvements are chiefly in the details of the Bisschop engine, and are in some instances rather primitive. A secondary explosion-jet is prescribed for high pressures. But this had been previously done. The specification is useful as a suggestion of cheap construction, one main fault of gas engines being that they are quite too dear. No. 614 of 1882 is the patent granted to W. B. Haigh and J. Nuttall for 'Improvements in the construction of gas engines.' They propose to use two cylinders in line, and that the charge shall act on both at the same time. In the ignition valve of this engine, shown in fig. 195, *q q* is a casting in which a conical cavity, *r*, is formed. This casting is screwed to the outside, and the cavity is so formed that its lower side is horizontal, or nearly so. On it a ball, *s*, rolls, but is prevented from having too much play by a stop-pin, *t*. At the apex of this conical cavity there is a small hole, *u*, leading into a peculiarly formed chamber or passage, *v v*, in which is a gas-flame that is constantly burning from a Bunsen burner, *w*, there being a free passage for the flame to ignite the mixture in the cylinder. The moment ignition ensues, the ball *s* is forced against the apex of the conical cavity by the expansion of the gases, and the passage *u* to the flame is stopped, thus preventing the light from being put out. The ball *s* then rolls down again by its own gravity, which allows the flame again to ignite the mixture in the cylinder, and so on at each stroke of the piston. This, though an ingenious, is a very precarious arrangement, and not equal to the flap or mushroom valve used in some gas engines. No. 703 of 1882 is a patent granted to

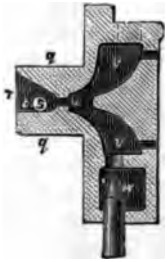

Fig. 195.—Haigh and Nuttall's ignition valve.

C. T. Wordsworth and H. Lindley for ‘Improvements in gas engines.’ One improvement is the interposition of a valve between the explosion chamber and the working cylinder. Using a flushing charge of air is another, but there is nothing new in this. No. 994 of 1882 is a patent granted to J. Fielding for ‘Improvements in gas motor engines.’ A piston is used to expel the products of combustion, a sliding stuffing-box, and electric lighting: nothing new. No. 1,026 of 1882 is a patent granted to P. Niel for ‘Improvements in gas engines. These improvements are—1st, utilising the outer part of each piston to blow out the products of combustion; 2nd, the combination of regenerators with gas engines; 3rd, the combination of valves adapted for regulating the gas supply. No. 1,318 of 1882 is the patent granted to C. G. Beechey for ‘Improvements in gas motor engines.’ The primary object of this invention is to remove the whole of the products of combustion from a gas motor engine after each explosion, and, at the same time, to provide a sufficient space or clearance behind the piston, when at the end of its stroke, to contain the charge of compressed combustible mixture for the next explosion. The invention consists in displacing by a small charge of combustible mixture the products of combustion which the working piston is unable to drive out of the cylinder. No. 1,360 of 1882, is a patent granted to H. Sumner for ‘Improvements in gas motor engines.’ There is nothing new in this patent except in the details. Projecting the igniting flame into the working cylinder, by causing a small portion of the compressed combustible charge from such cylinder to pass directly across the igniting flame opposite to the entrance of the cylinder port, is one of the earliest lighting expedients. R. Skene (No. 1,590) of 1882 patented ‘Improvements in gas motor engines.’ In this arrangement it is intended to dispense with the water-jacket or any cooling medium in or about the working cylinder, so as to retain and utilise the heat generated by explosive combustion. Explosion chambers of special form are attached to, but are separate from, the working cylinders. The piston is a non-conductor, and there is a simple ignition valve. The exploding chamber is preferably a tube of small diameter. The cylinders are fitted with trunks. J. A. Drake and A. Muirhead patented No. 1,717 of 1882, being ‘Improvements in and connected with gas engines.’ In addition to the usual piston which gives motion to the crank, there is a second, or displacer, piston within the cylinder, for the purpose of expelling the products of combustion. This had before been done by many persons.

F. Anderson and F. W. Crossley obtained a patent, No. 1,754 of 1882, of which the purpose was to render the ignition of the gas more certain in the ordinary ignition arrangement of gas engines. A coil of wire is directed to be introduced into the cavity which contains the ignited gas, among which a jet of gas is introduced at the time the cavity is in communication with the external kindling flame. A is the external flame, which is maintained in a cavity of the slide-cover, usually having above it a chimney, *a*, to create a little draught through the passages; B is the slide, having formed in it the igniting cavity C, which has a side aperture, c^1, towards the cylinder, and a side aperture, c^2, towards the flame cavity of the cover, and also another passage, D, leading to the ignition cavity C; this passage having a side aperture, *d*, towards a channel, E, formed in the slide-cover, and supplied with gas from the main supply. Within the ignition cavity C, in the part of it next to its communications with A and D, a coil or bunch of wire, F, is fixed. The slide B, by its movement, brings the apertures c^2, c^3 as shown, for a moment into coincidence with the corresponding apertures in the slide-cover, and, at the same moment, E communicates through *d* with D, so that a stream of gas, entering by D, and mixing with the air in C, is kindled by the exterior flame A, producing a flame in or about the wire F. The slide then, moving onwards, cuts off communication by c^2, c^3, and *d* with the passages in the slide-cover, and opens communication by the aperture c^1 with the cylinder containing the combustible gaseous charge, which is ignited by the flame or heat retained in the ignition cavity C, the wire F maintaining sufficient heat for this purpose. C. M. Sombart (No. 2,057 of 1882) patents 'Improvements in gas engines,' in which he

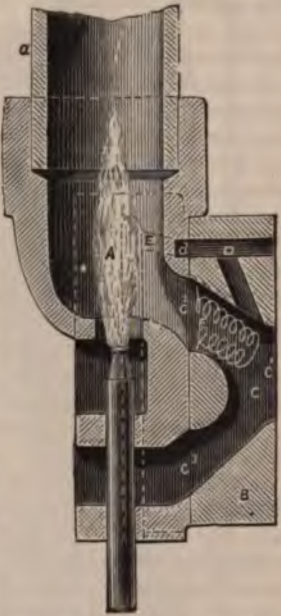

Fig. 196.—Anderson and Crossley's Gas Engine.

specifies a number of small details of little novelty or importance. S. Worssam (No. 2,126 of 1882) patents 'Improvements in gas motor engines,' in which a pump for compressing the combustible mixture is placed in the same line as the cylinder of a horizontal gas engine, and the pistons of cylinder and pump are fixed upon the same rod. The general arrangements are eligible enough, but there is no feature of novelty or importance in them. S. Clayton (No. 2,202 of 1882) patents 'improvements in motor engines worked by gas or combustible vapour and air.' These engines are, by preference, double-acting and horizontal. There is a pump having a shorter stroke than the engine, and the piston of which is set in advance of the piston of the engine. There is a firing or igniting chamber at each end of the cylinder, lined with non-conducting and incombustible material. There is little that is novel in the arrangements proposed. Oliver Mobbs (No. 2,257 of 1882) patents 'Improvements in gas engines' of no utility. W. B. Hutchinson (No. 2,329 of 1882) patents 'Improvements in gas engines' of no utility. S. and H. N. Bickerton patent 'Improvements in and applicable to gas motor engines' (No. 2,345 of 1882). The alleged novelty is a displacer piston for expelling the products of combustion.

Q. A displacer piston seems to be a favourite expedient?

A. Yes; and its function is not uniform. Sometimes such displacer is merely a feed pump for air.

Q. Of course some species of feed pump is necessary in every case?

A. No doubt; but sometimes the cylinder acts as such. H. Davey (No. 2,527 of 1882) patents 'Improvements in apparatus for the production of inflammable gas, and applying its combustion for the production of motive power.' The gas-producer consists of a strong cylindrical vessel, lined at its lower part with refractory material, A (fig. 197), and having in its upper part an annular water-casing, B. The fuel is fed from time to time through a hopper-valve, C (which is kept cool by a water-casing), and rests on the perforated refractory bottom, D, the interior of which is supplied with steam by a pipe, *d*, leading from the steam space of the casing B, and with compressed air by the pipe d^1, from the air reservoir, both supplies being regulated by suitable stop-cocks or valves. The fuel can be stirred by the poker-rod *a*, introduced through a stuffing-box. The ash falls into a space at the bottom, whence it is proposed to be removed from time to time by a water-cased valve, C^1. There is a great deal of ability displayed in this patent, and the gas-producer shown in fig. 197 is one of the best projected. Nevertheless it is easy to see that it could not be made to work practically in the way the inventor intended. In the first place, the valve at the top, through which the coal is to be introduced, could not be expected to be kept tight under any considerable pressure, exposed as it would be to the scratching and dust of coal being continually fed in against delicately finished surfaces. The poker, too, which is to be worked through a stuffing-box, would be too circumscribed in its movements to be efficient in breaking up a caking fire, and the clinker would settle upon the perforations of the shield, D, and hinder the passage of air or steam through them. As the result of a most extensive series of experiments with producers intended to supply carbonic oxide gas under pres-

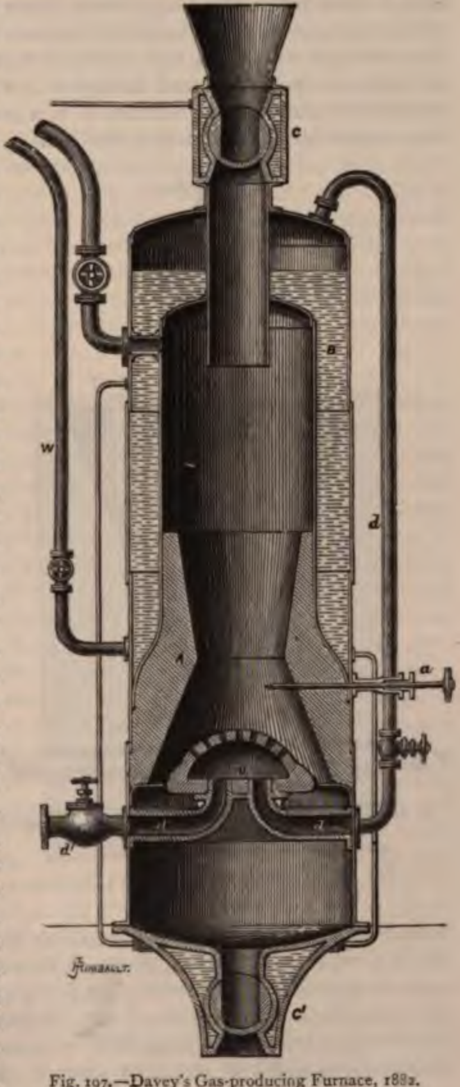

Fig. 197.—Davey's Gas-producing Furnace, 1882.

sure, I have found the arrangement shown in fig. 198 to be that which best answered its intended purpose. A is a water-jacketed pipe through which the fuel, which is in the form of coal-dust, is continuously fed in, and through which it may be shot in by a stream of air of high pressure; B is a prolongation of the furnace upwards, through which the fuel is carried into the tube C, past the throat D, to the lower part of the furnace, in which part an active combustion is maintained; E E are water-pipes to prevent the throat of the furnace from being melted by the intense heat, and F F are the tuyères through which air mingled with a little finely powdered chalk or lime is sent into the furnace; G G are small supplementary tuyères, of which the function is to keep the clinker, which becomes fluid by the introduction of the lime, in a molten state, in order that it may overflow at the orifice H, which in its action resembles the dam in an iron-smelting furnace, through which the slag runs out. The air blown in through G G is mixed with a small quantity of petroleum, but for which the clinker would be blown black by the blast of air. It has been found that the coal-dust, fed into this furnace, does not cake, however bituminous the coal from which it has been derived; and the carbonaceous

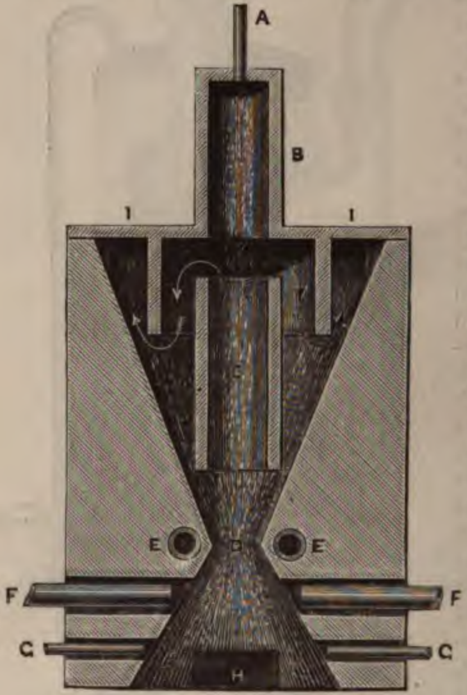

Fig. 198.—Carbonic Oxide Coal Dust Furnace by J. Bourne, 1872.

particles are projected upward through the tube c, and being then constrained to move downward by the spark-catcher arrangement, they are carried by their momentum towards the throat of the furnace, while the gas thus separated from them passes onward in the direction of the arrows. A constant circulation of the minute carbonaceous particles is thus maintained until they are consumed; and the infusible residuum being rendered fluid by the lime, which acts as a flux, runs away as slag, thereby enabling the action of the furnace to be maintained unimpaired. Instead of being made of brick, the furnace may be made of iron surrounded by water, and such a furnace has been found in practice to generate carbonic oxide under pressure without being embarrassed with the inconveniences which necessarily occur where pieces of coal have to be fed in through a valve or door.

Q. What other patents were taken out in 1882?

A. There are a good many more. No. 2,753 of 1882 is a patent granted to C. T. Wordsworth and J. Wolstenholme for 'Improvements in gas-motor engines,' in which flushing the cylinder with air to get rid of the products of combustion is the chief feature: other details are of little novelty or importance. C. Beissel, No. 3,435 of 1882, patented 'Improvements in gas-motor engines,' in which he also flushes the cylinder with air. He also modifies somewhat the ordinary lighting arrangements. H. P. Holt and F. W. Crossley, No. 3,449 of 1882, patent improvements which contain nothing of any importance. T. Hargreaves, No. 3,540 of 1882, patents 'Improvements in thermo-dynamic engines.' The apparatus described is complex, and the arrangements imperfectly digested. The claim is 'in regenerative caloric engines in which gaseous liquid or solid fuel is used, working substantially in the following order or sequence: (*a*) compressing atmospheric air, (*b*) saturating such air with water-vapour, (*c*) superheating the said compressed saturated air in a regenerator, and further superheating by combustion, and (*d*) using the said compressed saturated, superheated, and burnt air to propel a piston or its equivalent.' No. 3,819 of 1882 is a patent granted to T. McGillivray for 'Improvements in gas engines,' in which there is nothing new. No. 4,378 of 1882 is a patent granted to J. Atkinson for 'improvements in gas engines,' in which he refers to a previous patent, No. 4,086 of 1881. There is nothing new in this one. No. 4,388 of 1882 is also for 'Improvements in gas engines.' There is nothing novel in it. No. 4,489 of 1882 is a patent granted to

F. W. Crossley for 'Improvements in gas-motor engines,' in which the charge is ignited by sending a lighting mixture through a heated U-tube of platinum or other similar metal. No. 4,948 of 1882 is a patent granted to D. Clerk for 'Improvements in motive-power engines.' He refers to a previous patent, 1,089 of 1881; the ignition arrangements of the present patent being the same as in that. For large powers, where economy of gas is important, compression, it is stated, should be used; but for small powers this condition may be neglected. No. 5,510 of 1882 is a patent granted to J. Maynes for 'Improvements in gas-motor engines.' This is a most elaborate specification, enumerating seventeen different heads of improvement, of which the most important seems to be the use of telescopic cylinders with a small space between them, to keep the lubricated surfaces sufficiently cool without the use of a water-jacket. The resulting engine, however, though exhibiting much inventive resource, is far too complicated for general use. No. 5,782 of 1882 is a patent granted to W. Watson for 'Improvements in gas engines,' which provides a lifting valve at the end of the cylinder for letting out the products of combustion at the right moment. For exploding arrangements he refers to patents No. 1,723 and No. 2,919 of 1881. A small force-pump is employed to force a charge into the cylinder for starting the engine, which, however, had been proposed before. No. 5,819 of 1882 is a patent granted to G. Whittaker for a gas lighting valve of no visible advantage. No. 6,130 of 1882, a patent granted to V. J. Laurent for 'Improvements in gas engines,' is a very judicious and well-digested arrangement. The objects proposed to be attained are all good, but not novel; and the resulting mechanism is more complex than is advisable. There is a hot cylinder fitted with a plunger, and a cold cylinder or pump of the same diameter as the hot cylinder and in the same line; so that one piston-rod does for both. The hot cylinder is cooled by passing the compressed gas through a double external jacket which surrounds it; and there is a perforated distributing diaphragm at the upper end of the hot cylinder. A tubular regenerator or heater is employed to heat the entering air by the escaping products of combustion, and the lighting is effected by a coil of platinum wire made incandescent by electricity. This concludes 1882 and brings us to 1883.

Q. What patents for gas engines were taken out in that year?

A. They become more numerous as we go on. The first patent granted is No. 326 to C. T. Linford and W. E. Cooke for 'Improvements in gas engines,' consisting of some modifications of the details, of little importance. No. 499 of 1883 is a patent granted to G. W. Weatherhogg for 'Improvements in air and gas-motors and apparatus for the production of gas therefrom.' It has been found, it is stated, that difficulty occurs in clearing the cylinder of the products of combustion. To effect this, two combustion chambers or reservoirs are employed; so that one may be cleared of the products of combustion while the other is generating them. One way of doing this is by a piston; another is by a blow-through action with air or steam. This is a very thoughtful specification, and exhibits an adequate acquaintance with the subject to which it relates: it refers to a previous patent, No. 4,402 of 1881. No. 638 of 1883 is a patent granted to C. W. King and A. Cliff for 'Improvements in gas-motor engines.' The chief recommendations are flushing or washing out the cylinder by air, and providing a small chamber at the end of the cylinder into which the explosive mixture enters, and which is lined with intractable material and provided with two small platinum spirals, which keep the gas introduced in a state of ignition. The flame strikes back when a small outlet valve is closed, and ignites the charge within the cylinder. The platinum spirals must be heated at starting. No. 645 of 1883 is the patent granted to James Robson for 'Improvements in motive-power engines.' There is nothing of any novelty or importance in this patent. No. 979 of 1883 is the patent granted to N. de Kabath for 'Improvements in gas and other engines.' The design here given is intended for fast and cheap engines, and it exhibits competent skill, and reflects much credit upon the patentee. But it is doubtful whether the engine is sufficiently simple to be very cheap. The nature of the arrangements will be best explained by the aid of the illustrations:—Fig. 199 is a vertical section in the plane of the crank-shaft, and fig. 200 a vertical section in a plane at right-angles with the crank-shaft; fig. 201 is a detail of the governor; fig. 202 a horizontal section through the ignition port and valve; fig. 203 an elevation of the ignition apparatus; fig. 204 a horizontal section of the piston; and fig. 205 a plan of the main inlet valve for air. The engine, it will be seen, is vertical, with two cylinders of different sizes, cast in one piece and fitted with trunk pistons. A is the working piston; S, water-jacket; B, the vacuum piston; C, the crank; E, piston valve carrying igniting-flame worked by an eccentric, X, and rod, W. The valve dips into the oil cup, Y; *d* is a by-pass leading to chamber *a*,

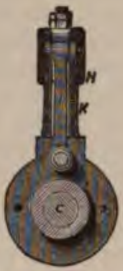

Fig. 201.—Detail of Governor.

- C. Engine shaft.
- H. Centrifugal weights.
- I. Roller tappet.
- K. Spring.

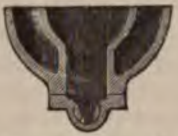

Fig. 202.—Horizontal section through Ignition Port and Valve.

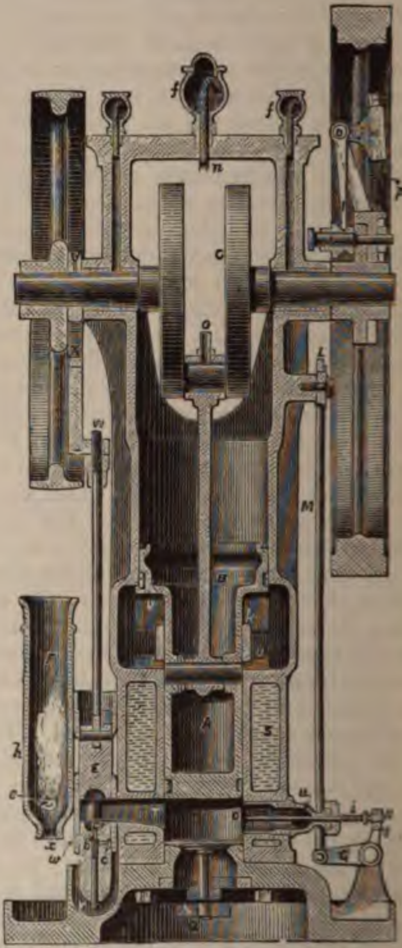

Fig. 199.—N. de Kabath's Gas Engine. Central vertical section parallel to the Crank Shaft.

and controlled by plug *b* communicating with cavity *c*, by which ga escapes from T into *a*. F is a chimney with contracted air inlet *x* *e*, igniting flame; *h*, air inlet to blow flame *e* to aperture *g*. D, inlet for gas and air—or gas only—from pipe *u*, admission controlled by O, closed by spring on rod *i*, on lever G, moved by rod M, connected with roller L. N, screw for adjusting lift of O, and *t*, set screw,

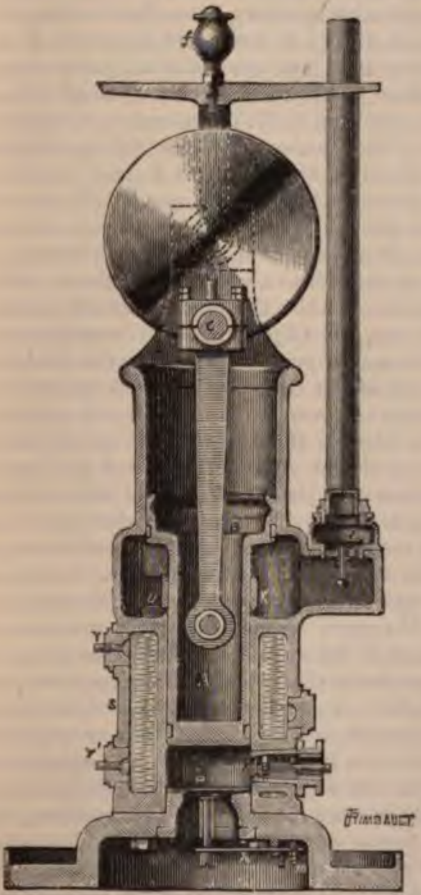

Fig. 200.—Vertical section at right angles to the Crank Shaft.

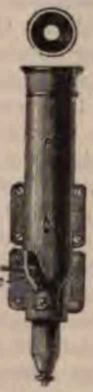

Fig. 203.—Elevation of Ignition Apparatus.

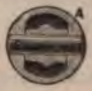

Fig. 204.—Horizontal section of working piston.

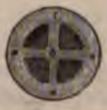

Fig. 205.—Underside plan of the Guide for the Main Inlet Valve Q.

I is roller tappet controlled by governor H; *ff* are oil cups, and *n* a wick to oil crank pin through wiper *o*. No. 1,060 of the year 1883 is the patent granted to F. von Martini for 'A new gas-motor.' This patent exhibits considerable ingenuity, but no feature of novelty or importance. No. 1,098 of 1883 is the patent granted to E. G. Wastfield for 'Improvements in, and applicable to, gas engines.' Nothing novel or important is propounded. No. 1,116 of 1883 is the patent granted to R. Steel and H. W. Whitehead for 'Improvements in gas engines.' They make the piston hollow, and the charge is compressed into it before explosion instead of into a chamber at the end of the cylinder: nothing new. H. Townsend and E. and E. C. Davies (No. 781) patent 'Improvements in gas-motor engines.' In a horizontal engine there are two cylinders, so arranged that one end of each forms a working cylinder in which the motive power is generated, while the other end forms a compressing pump. E. Butcher, No. 1,835, patents 'Improvements in gas-motor engines.' He uses a pump to withdraw the products of combustion at the end of the stroke. G. G. Picking and W. Hopkins patent, No. 2,492, 'Improvements in gas-motor engines,' which mainly consist in blowing through with air before introducing the next explosive charge. W. B. Haigh and J. Nuttall, No. 2,057, use two cylinders and pistons of different sizes to more effectually expel the spent gases. L. H. Nash, in the patent No. 2,561, gives a long and complex specification. It describes a gas engine in which provision is made for slow combustion instead of explosion, and the gas and air enter separately. E. Körting and G. Leeckfield patent, No. 2702, 'Improvements in gas-motors.' They specify modifications in the way of introducing the gases, of igniting them, and of governing the speed. The suggestions are thoughtful and judicious, but not very important. E. and E. Crowe patent, No. 2,706, 'Improvements in gas-caloric motive engines.' In this patent the chief feature is the application of a regenerator to gas engines. There are two separate compressing pumps—one to compress the air, and the other the gas. After compression, the gas is passed into the bottom of a reservoir, which is lined with refractory material, and where it is mixed with just sufficient air to ensure perfect combustion. The greater part of the air delivered by the pump is passed into the said reservoir, at a distance from the gas inlet sufficient to allow the first mixture to undergo perfect combustion, and then diluting the products sufficiently to enable them to be conveniently employed in a working cylinder without having recourse to water-jacketing. At the bottom of the reservoir there is a door through which ignited coke can be introduced for lighting the gas when the engine is started. The refractory material, after it becomes hot, will continue the combustion. The gas and air pumps have together the same sectional area as the working cylinder, and are concentric, the one with the other. It is stated that it is convenient to make the hot-air reservoir and the regenerative chamber of equal capacities. The arrangements are thoughtful, and the design altogether is far above the average quality of such productions. S. Marcus patents, No. 2,790, 'Improvements in gas-motor engines.' These purport to be some rectifications of a patent granted in 1882 (No. 2,423). But neither patent contains anything of importance. C. Ingrey patents, No. 2,801, 'Improvements in caloric engines.' This patent specifies various improvements in the details, one of which is the use of slide valves of plumbago with metal lips. F. H. W. Livesey, No. 2,927, patents 'A new or improved gas-motor engine'—the improvement consisting in the application of a regenerator. C. H. Andrew, No. 3,066, patents 'Improvements in gas-motor engines,' the object of which is to produce an explosion at each revolution of the engine. A preliminary explosion is accomplished in a small chamber, the force of which is sent into the cylinder, as the valve by its motion a little further opens a passage. This had been done before. The products of combustion are expelled from the cylinder by the inrush of the next charge of explosive mixture. This, however, in other cases had not been found to be sufficient. The engine is, on the whole, well-designed. There is a horizontal cylinder on each side of a horizontal shaft, one of which cylinders acts as a pump, while in the other the power is generated by the explosion of the compressed gases. J. Fielding, No. 3,070, specifies 'Improvements in gas-motor engines,' one of which is the application of a small supplementary cylinder instead of the usual space left at the end of the horizontal cylinders of gas engines, this supplementary cylinder being useful for the expulsion of spent gases. There is also some variation from the usual lighting arrangements. L. M. Martin and F. W. Gilles patent, 3,071, 'Improvements in heated-air motors,' but there is no visible superiority in their arrangements over others which had been projected before, and all the novelty claimed is for the arrangement of the details. F. W. Crossley in his patent, No. 3,079, specifies two Otto engines placed side by side, and working on to the same crank: a small matter to take a patent for! P. Niel, No. 3,135, patents 'Improvements in the construction and arrangement of gas engines.' This project is designed to vary automatically the volume of mixture of gas and air, and its compression before ignition, the mixture being in each case of the same proportions. The arrangements are very judicious, and the engine is well-designed, and ought to be an efficient and satisfactory motor. W. Foulis, No. 3,280, patents 'Improvements in gas engines,' one of which is the use of an instrument for adjusting the proper proportions of gas and air, and which he calls a 'mixing meter.' Several improvements in the details of gas engines are described, some of which are emendations of a previous patent, No. 180 of 1881. The igniter employed is a tube of fire-clay, which becomes heated by the gas, and which re-ignites the flame if blown out. The various patents of this inventor exhibit conspicuous ability. C. F. L. Gardie, No. 3,383, patents 'Improvements in gas engines,' in which the cylinder is lined with refractory material. For igniting the gas a metal tube of small diameter is provided with a platinum burner supplied with explosive mixture from the reservoir, and from which a jet of flame, constantly burning, is directed upon a platinum wire, which is thereby maintained at a white heat. A regenerator, also, is employed. But there is nothing sound in the provisions of this patent, and the drawing appended to it is of the crudest character. C. T. Wordsworth and H. Lindley patent, No. 3,568, 'Improvements in gas-motor engines,' which relate chiefly to emendations in a patent, No. 2,181 for 1880. The working and charge-pistons are arranged in a similar manner to that adopted in Brayton's patent, No. 432 of 1872. But the compression piston is made larger than the working piston, to enable a larger volume of combustible mixture to be used. The engine is well designed, but exhibits little novelty. J. A. Serrell patents, No. 4,242, 'Improvements in gas engines.' We have here a verbose specification with little novelty. It prescribes the ignition of a charge of compressed air and gas in a cylinder, by the explosion of a separate smaller charge not under compression—an arrangement made by several persons before this date. The Economic Motor Company of New York patent, No. 4,260, 'Improvements in gas engines.' But the specification, though elaborate, contains no feature of novelty. C. H. Andrew, No. 4,291, patents 'Improvements in gas engines,' consisting of the introduction of a check valve between the slide and the cylinder, so as to take off the slide the pressure of the explosion. A rather narrow basis, this, on which to rest the pretensions of a patent! M. V. Schiltz, No. 4,455, patents 'Improvements in gas and petroleum engines,' consisting of various emendations in the patent No. 3,330 of 1881. Nothing material is here described. T. M. Williamson, J. Malam, and W. A. Ireland, No. 4,816, patent 'Improvements in gas-motor engines,' several of which are emendations of previous patents. The engine resulting is well-designed, but does not contain many features of novelty. The lighting arrangement consists of a metallic tube, heated externally by a Bunsen burner. During the compression of the charge, a small stream of the mixture escapes outwardly and burns at the mouth of the hot tube. The products of combustion coming from it escape into the atmosphere through a small valve, which, when suddenly shut, causes the flame to strike back and ignite the charge in the cylinder. C. A. Bullock, No. 5,085, patents 'Improvements in gas-motor engines,' but there is nothing of novelty in them. H. C. Bull patents, No. 5,113, 'improvements in gas engines.' These improvements relate to that kind of gas engine in which an effective stroke is obtained for every revolution of the crank in a single cylinder, in which a primary and secondary piston work. The cylinder consists of two concentric vessels, the outer one of which is cast, and is provided with the necessary ports. The inner vessel is a steel tube, and forms the working cylinder. For the ignition of the combustible charge a slide valve is employed, having two chambers, one of which serves as a reservoir while the other is a flame-pocket. The engine is well-arranged, and the hand of a competent engineer is discernible in it. W. E. Hale in his patent, No. 5,265, employs an electrical igniter, so that the charge may be fired near the centre instead of at the side of the cylinder; but there is no material novelty in the general design. Julius Söhnlein, 5,297, patents 'Improvements in petroleum motors.' A jet of petroleum is injected into a vessel of compressed air, and is fired by electricity. The project is well-conceived, but the plan received provisional protection only. W. Schmidt patents, 5,317, 'Improvements in hot-air engines,' in which a reservoir of liquid is used, into which the surplus heat is to be introduced, and the steam thence resulting is to close a valve which admits air to the grate to maintain the combustion. G. G. Picking and W. Hopkins patent, No. 5,406, 'Improvements in gas-motor engines.' This refers to a previous patent, No. 2,492, of the same year, and of which the present contains some emendations. But there is nothing novel or material in it. L. H. Nash, No. 5,543, patents 'Improvements in the construction of gas engines.' This specification intimates that the best authorities on gas engines allege that, of the total heat consumed in gas engines, about 16 per cent. is utilised; 51 per cent. being abstracted by the water jacket, and 31 per cent. carried away by the educted gases, while 2 per cent. is lost in radiation. The indications sought to be fulfilled are judicious enough, one of them being to work at a very high pressure. But the modes prescribed of giving effect to the resulting aspiration do not appear likely to come into use. In the same year the same person took out two other patents, Nos. 5,632 and 5,633, in one of which is figured a three-cylinder engine, resembling Brotherhood's arrangement, but which is to be worked by gas instead of steam. All the forms, however, appear to be too complex and costly to be likely to come into use. S. Wilcox patents, No. 5,636, 'Improvements in hot-air engines.' The specification exhibits competent engineering skill, and is very elaborate and well-considered. But, in common with all hot-air engines, it is bulky relatively with the power generated, and it is deficient in simplicity. E. C. Mills patents, No. 5,721, 'Improvements in gas-motor engines.' These improvements consist chiefly of immaterial details. To ignite the charge, a thimble of platinum is employed, which projects into a small chamber that communicates through a valve with the explosion-chamber in the cylinder. Projecting into the thimble is a burner fed with compressed mixed gases. To make sure that the heat will be maintained, it is necessary to obtain a diffusion of the issuing gases, and for this purpose layers of platinum wire gauze, or spongy platinum, porous earthenware, or asbestos are employed opposite to the jet. C. M. Sombart patents, No. 5,923, 'Improvements in gas engines.' One source of imperfection in gas engines is the difficulty of adjusting the power generated to the work to be done. A common mode of doing this is by making more or fewer effective strokes in the minute. But in this patent it is proposed to have two cylinders, and to throw one of them out of use when the power generated is too great. The proper course, however, is to regulate the admission of air and gas to the power required. The composition of the explosive mixture should be the same, but there should be more or less of it used as the power needed is great or small.

Q. In looking back upon this array of contrivances for the supersession of the steam engine, will you state what the practical result has been of such a large expenditure of ingenuity?

A. Up to the present time the benefit attained has been insignificant. Air or gas engines of small power have been introduced in some of those cases where the chief expense to be encountered is the wages of an attendant; for whereas when a steam boiler is employed a man is generally required to attend to it, to replenish the furnace with coal and to regulate the supply of the feed water, most of this attention can be dispensed with in the case of an air or gas engine, which, once lighted and started, requires little further care. The saving thence resulting, however, is not a saving in fuel or machinery, but in the cost of the attendant's wages. In the case of large powers this benefit would not be realised, as, with engines of any kind, if of considerable size, an attendant's services will be necessary to oil the bearings of the engine and of the shafting it drives, to see that the brasses are neither too tight nor too slack, so as to create heating or knocking, and to perform various other services which in the case of small powers may be deferred or delegated with scarcely any appreciable cost for wages. The preference given to air and gas engines in certain cases is almost wholly upon this ground, and such engines have not yet been successfully introduced in any case in which a large power is required.

Q. Is there any insuperable impediment to their adoption for large powers?

A. I believe there is in the case of air engines, and this impediment is created by the circumstance that air is a very bad conductor of heat. The difficulty of heating it in any possible air boiler is so great, and involves such weight and magnitude of apparatus, that there is very little probability of such a system being adopted for large powers. In the case of gas engines where the air is heated by internal combustion, this difficulty is avoided. But coal gas is a costly fuel, and although carbonic oxide may eventually be introduced in substitution of it, yet this carbonic oxide would have to be made in a separate apparatus, involving cost and complication; and with carbonic oxide a very much larger engine would be necessary to generate the same power. While, therefore, I believe that the present steam engine will eventually be superseded by a thermo-dynamic engine, which with less machinery will generate the power with less cost, and while I am further of opinion that such a result is near at hand—the means for its attainment being, in fact, already visible—I do not discern in any of the projects which have been hitherto propounded the combination of the necessary qualities to effect this great amelioration.

Q. What, then, are the qualities necessary?

A. To render more clear what remains to be done in this direction, it will probably be the best course to recapitulate what has been practically accomplished already. We shall thus be able to see where we stand, and the lines of successful progress in the past may be projected into the future, indicating by their convergence the point which we wish to fix and to overtake.

PRACTICAL RESULTS AND FUTURE PROSPECTS.

Q. Will you state, then, what have been the best results in regard to the performance of air and gas engines which have been practically reached up to the present time?

A. The earliest important success was that obtained by the Rev. Dr. Robert Stirling, who in 1816 invented the regenerator and applied it to an air engine, subsequently patented by him and his nephew James Stirling, as narrated in the historical sketch already given. In this engine the heat was applied to the bottom of the cylinder, which was made hemispherical; and from the small area of the heating surface and the imperfect conductivity of the air, the bottom of the cylinder was soon worn out from the high temperature to which it was subjected. Nevertheless this engine attained a measure of practical success quite equal to any that has since been reached by air engines. Several of Stirling's engines were made, and one of them drove the machinery of the Dundee Foundry for many years. Of this engine a description was given by Mr. James Stirling before the Institution of Civil Engineers, in 1845. The cylinder was of 16 inches diameter and 4 feet stroke, and the engine, which was double-acting, made 28 revolutions per minute. The power generated, as ascertained by a friction brake, was 45·45 horses power, or, adding one-tenth for the friction of the engine, the indicated power was 50 horses. The coal consumed per hour was 183·3 lbs., which gives a consumption of 1·66 lbs. of coal per horse-power per hour. But steam engines have long worked with an economy equal to this, and are not subject to the same disability from the bottom of the cylinder being speedily worn out and having to be so often renewed.

Q. What was the temperature of the air used?

A. The temperature of the working air was 650°, and of the exhaust 150° Fahr. The maximum pressure was 240 lbs. per square inch, and the mean effective pressure was 37·75 lbs. In this engine the volume of the motive air remains constant, and, in fact, the same air is permanently retained. But the temperature of the air is changed, and consequently the pressure, by sending it through the regenerator, either to deposit its heat as it goes out of the cylinder or to regain its heat as it comes in. In Ericsson's engine the pressure is constant, but the temperature, and consequently the volume, is changed.

Q. What result has been practically obtained by Ericsson in his air engines of large size?

A. About 1852 the steam ship 'Ericsson' was constructed with 4 cylinders, each 14 feet diameter and 6 feet stroke. The working pressure of the air was 2·12 lbs. per square inch. The collective indicated power of the engines was 300 horses, and the consumption of coal per horse-power per hour was 1·87 lbs. The air was heated by the application of a fire to the bottom of each cylinder, and the bottoms of the cylinders were domed upwards instead of being bellied downwards as in Stirling's arrangement. The engines of Stirling and Ericsson have been the most successful air engines that have been tried. An engine constructed by Sir George Cayley, and worked by the products of combustion from a furnace, was very soon disabled by injury to the cylinder, piston, and valves from the high temperature and the dust

Q. Before we can compare the performance of air engines with that of gas engines we must know what are the respective heating powers of a pound of coal and a pound of gas?

A. That is so.

Q. You have already stated that a pound of carbon will raise a pound of water about 14,500° Fahr?

A. Yes, and a pound of good coal will give about the same result. The composition of coal gas varies somewhat in different towns. But a pound of London gas will raise a pound of water 22,500° Fahr., so that it will be 1·55 times more effective than coal in the generation of heat. The volume of a pound of this gas at the atmospheric pressure and at 60° Fahr. will be about 35½ cubic feet. As the dynamical value of the heat which raises a pound of water 1° Fahr. is 772 foot-pounds, the dynamical value of the heat which raises a pound of water 22,500° Fahr. will be 17,370,000 foot-pounds. A horse-power is 33,000 pounds raised one foot high per minute, or 1,980,000 foot-pounds expended per hour. If the whole heat of a pound or 35½ cubic feet of gas burnt per hour were turned into mechanical effect the power generated would be equal to 8·8 horses, or 1 horse-power would be produced by an expenditure of 4 cubic feet of gas per hour. But no result has been yet attained which comes near this.

Q. Then state what result has been actually attained?

A. The engines of Lenoir and Hugon were experimentally tested by Tresca, who found that the actual amount of gas required per hour to generate 1 horse-power was in the Lenoir engine 140 cubic feet, and in the Hugon engine 85 cubic feet. Indicator diagrams taken from the Lenoir engine are given in figs. 206 and 207. These

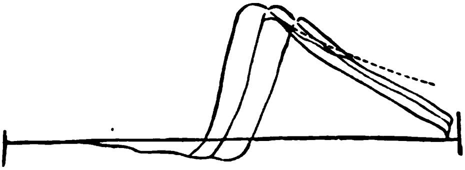

Fig. 206.—Diagram from Lenoir's Gas Engine. Cylinder 8½ inches diameter and 16½ inches stroke; 50 revolutions. Scale 1 inch=32 lbs.

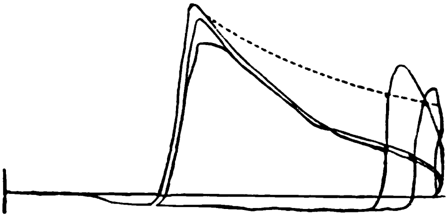

Fig. 207.—Diagram from Lenoir's Gas Engine. Cylinder 8½ inches diameter and 16½ inches stroke; 45 revolutions. Scale 1 inch=32 lbs.

diagrams show several things. One is, that notwithstanding the large loss of heat through the sides of the cylinder from the use of the water jacket, the pressure is nevertheless maintained in much the same way as if there were no such loss, which is accounted for by the dissociation which takes place at high temperatures and the recombination which takes place when the temperature is reduced. The gas engine differs from the air engine in this respect, that in the air engine any heat lost through the sides of the cylinder involves a corresponding loss of temperature within it, whereas in the case of the gas engine any reduction of temperature from this cause or from expansion is followed by the recombination of gases within the cylinder which had been dissociated by the high temperature of the explosion. By this recombination additional heat is generated, and so the temperature is kept up in much the same way as if no loss from the action of the water-jacket had occurred. A serious loss from this cause nevertheless takes place, amounting, it is reckoned, to 51 per cent. of the whole heat generated, but it does not reveal itself in the diagrams. The dotted lines are the adiabatic lines, or lines which would be traced if there were no leakage of heat through the cylinder sides, and the full lines are the actual diagrams. In Lenoir's engine the maximum temperature of ignition was 1,356° Centigrade, or 2420·8° Fahr., and it has hence been concluded that the combustible mixture used must have consisted of 1 volume of gas and 14 of air. But this conclusion does not rest on any sufficient evidence, as it is not known what proportion of the gas was actually burnt. In the early examples of Lenoir's engine, the best proportions of the explosive mixture were found to be one volume of gas to eight of air. The pressure at the moment of explosion should, with these proportions, be about five atmospheres. But the maximum pressure shown on the diagrams is not more than half this. From these and other indications it is clear that there is some serious source of loss in this engine other than from the jacket, and the probability is that, either from dissociation or imperfect admixture, a considerable proportion of the gas is dismissed unburnt.

Q. The distance between the short vertical lines in the diagrams at the end of the horizontal atmospheric lines of course represents the length of the stroke. In the first diagram the explosive mixture, which begins to enter at the beginning of the stroke, appears to be cut off at half-stroke, and in the second diagram a little earlier, at which point the explosion takes place. May not loss also occur from the explosion being unduly delayed?

A. It may; and in fig. 207 it will be observed some ignitions took place very late in the stroke, and the benefit of them was therefore nearly all lost. These misses were caused by the points through which the igniting electric spark was transmitted getting wet. It appears that the time occupied by the explosion was about one-twentieth of a second. But the rate will be slower with a mixture more diluted with air, or with the air and gas less intimately mixed.

Q. In the case of gunpowder of uniform chemical composition, may not the rate of explosion be made faster or slower by a suitable mechanical disposition of the particles?

A. It may.

Q. And in an explosive gas-mixture a similar effect may be produced by similar means?

A. Yes.

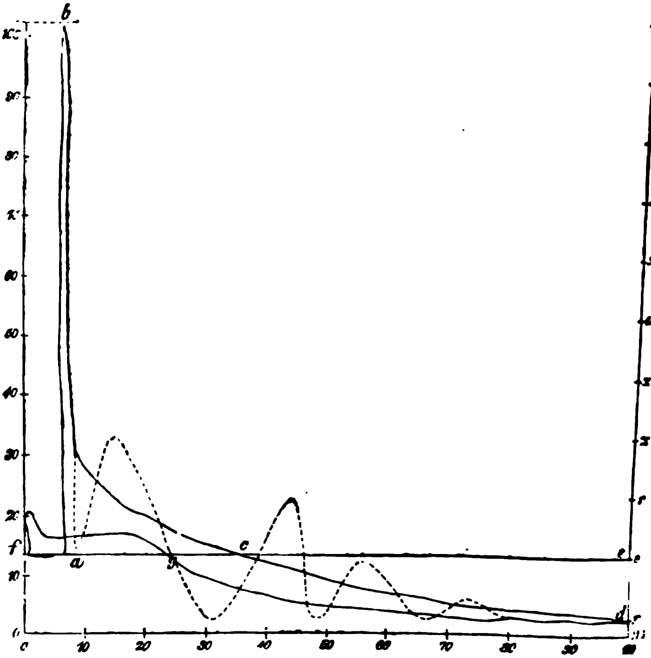

Fig. 208.—Indicator diagram of Otto and Langen's Free-piston Gas Engine.

Q. What is the ascertained performance of the Otto engine?

A. Otto and Langen's free-piston gas engine, in which a piston is shot up against the force of gravity like a ball projected from a gun, producing a vacuum behind it from which power is obtained. has been already represented in fig. 177, and in fig. 208 an indicator diagram of this engine is given. *fe* represents the atmospheric line. and from *f* to *a* a mixture of gas and air at atmospheric pressure is allowed to enter the cylinder. At *a* the mixture is ignited and the piston is propelled to *c*, at which point the pressure has fallen to that of the atmosphere. From *c* the piston moves to *e* with diminishing velocity, and thence returns, doing work represented in amount by the vacuum generated by the explosion acting on the area of piston, and by the weight of the piston and rack which have been shot up and now return. The vacuum power is represented in the diagram by the area *d c e*. In this engine the explosive mixture consisted of one volume of coal gas and nine of air, and a horse-power was generated by the expenditure of 35 cubic feet of gas in the hour.

Q. Has no result better than this yet been attained?

A. The results which are said to be better are not very clearly authenticated. In 1882 a paper was read by D. Clerk before the Institution of Civil Engineers, descriptive of his gas engine, fig. 193, in which it is stated that a horse-power has been obtained in this engine with a consumption of 22 cubic feet of gas per hour, and the Otto engine, fig. 178, is said to have attained the same result with 21 cubic feet per hour. A diagram taken from Clerk's engine is given in fig. 209. The diameter of cylinder was 6 inches, length of stroke 12 inches, and number of revolutions per minute 150. The mean available pressure was 70·1 lbs., and the power generated 9 indicated horses-power. The pressure of the mixture of air and gas before ignition was 41 lbs. Its temperature before compression was 60° Fahr., and after compression 270·9° Fahr. The temperature

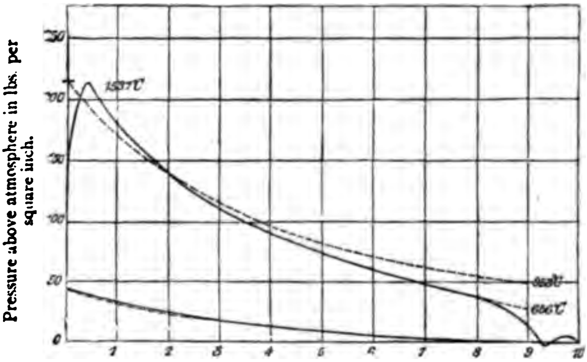

Fig. 209—Diagram of Clerk's Gas Engine.

of the explosion was 2,766·6° Fahr. and the maximum pressure produced by the explosion 220 lbs. The temperature of the exhaust was 1,176·8° Fahr. The lower dotted line in the diagram shows compression without loss of heat to the same volume that exists in clearance space, and the upper dotted line shows the work done by air heated to 2,766·6° Fahr., supposing it to lose no heat during expansion except by doing work. The near coincidence of this line with the actual line of the diagram shows that the large loss of heat through the cylinder sides has been compensated by the importation of heat from some other source, and the only conceivable source is either the gradual burning of gas not burnt by the explosion or the recombination of gases dissociated or prevented from combining by the high temperature of the explosion. Probably both of these causes are operative to some extent.

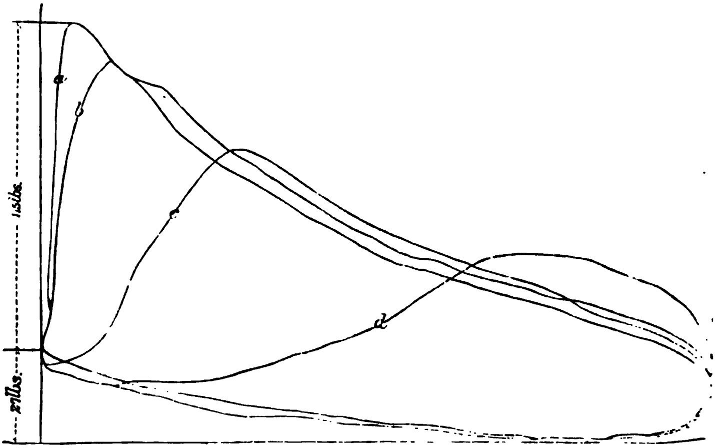

Fig. 210.—Diagram from an Otto Engine, showing that the speed of the piston may overtake the spread of the flame.

Q. In the case of slow ignitions in engines working at a high speed, may not the speed of the piston overrun the speed of the ignition?

A. Yes: and this sometimes happens as is shown by fig. 210, which is a diagram taken from an Otto engine, where *a* shows the line of rapid ignition where the point of maximum pressure is reached at, or close to, the beginning of the stroke. The line shows that the piston has moved a little way before the maximum pressure has been attained. In *c* and *d* this action is more pronounced, and it is easy to conceive that, by a still further postponement of the combustion, the maximum pressure of the explosion would occur after the termination of the stroke when the valve was open to the exhaust. As mechanical agitation accelerates mixture and combination, so the want of such agitation will retard them, as also will a large admixture of air with the gas, whereby its readiness to inflame will be diminished. In all hydrocarbon engines operating by explosion, it is desirable that such explosion should take place early in the stroke, as thus alone can efficient action be obtained.

Q. What dynamical result is obtained from engines worked by petroleum or other liquid hydrocarbons?

A. The heating power of the mineral oils is very nearly the same as gas, and the efficacy of petroleum engines should therefore be about the same as that of gas engines. If in a gas engine one horse-power can be produced by the combustion of 21 or 22 cubic feet of gas in the hour = ·6 lb. of gas, then, gas or petroleum being about 1·55 times more efficient than coal, we should have a horse-power produced by the equivalent of about 1 lb. of coal per hour, This is considerably less than the consumption in any steam engine; but it requires authentication. There is no doubt, however, that by the introduction of improvements which will obviate losses from known causes the existing economy will be largely augmented.

Q. May not much of the loss arising from the water-jacket be obviated by using a hot cylinder lined with some refractory material?

A. No doubt; but you would thus only transfer the loss to the exhaust. You would not with any manageable dimensions for expansion be able to get the heat out of the air.

Q. In conjunction with a hot cylinder you could use a regenerator to recover the heat which the exhaust dismisses?

A. That is true; but what use are you to make of the heat thus recovered? To increase the temperature of the air by which the combustion of the gas or petroleum is accomplished is tantamount to increasing the temperature of the combustion itself, and that is already so high as to prevent combination to a considerable extent until the temperature has been reduced.

Q. If petroleum engines can be made as efficient and economical as gas engines, how comes it that they have not been brought into more extended use?

A. One difficulty has arisen from the circumstance that mineral oils are not quite homogeneous, but consist of a mixture of different oils of different degrees of volatility. In the oil fed into the combustion chamber, therefore, the more volatile parts have been vaporised and burnt, while the less volatile parts have accumulated as a dense oil in the engine. The same difficulty has been experienced in the forms of apparatus for generating illuminating gas from mineral oils by carburising air.

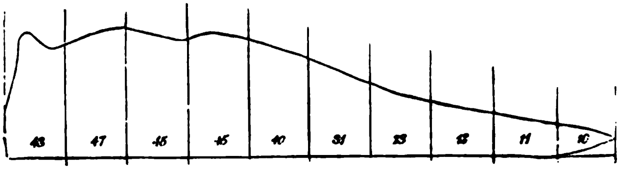

Fig. 211.—Diagram from Cylinder of Brayton's Petroleum Engine. Diameter of cylinder 8 inches; stroke 12 inches; mean pressure 30·2 lbs.

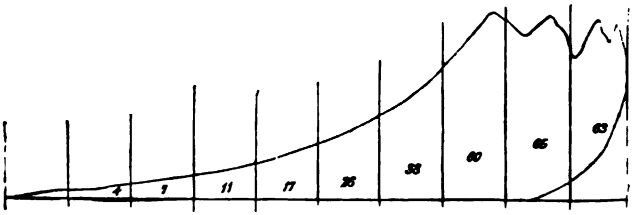

Fig. 212.—Diagram from the Air-compressing Pump of Brayton's Petroleum Engine. Diameter of pump 8 inches; stroke 6 inches; pressure in reservoir 60 lbs.

Q. What have been the results obtained by Brayton's petroleum engine of which a representation is given in fig. 179?

A. Diagrams from the cylinder and compressing-pump of Brayton's engine taken by Clerk are given in figs. 211 and 212, by which it will be seen that the maximum pressure in the cylinder is 47 lbs., and the maximum pressure in the pump 66 lbs. This is a continuous combustion engine. The air and petroleum are fed by separate pumps into a close vessel, where combustion takes place, and the engine is worked by the products of this combustion. The mean pressure on the piston is 30·2 lbs., and the mean resistance of the pump 27·6 lbs. per square inch. But as in this engine the stroke of the piston is twice that of the pump, the effective resistance of the pump will be reduced to 13·8 lbs. per square inch. In the engine shown in fig. 179 the cylinder and pump have the same stroke, but different diameters. It is clear that for all purposes of locomotion the gas engine is not applicable, and a petroleum engine, therefore, if made to operate with equal efficacy, has a large and special sphere.

Q. The Brayton engine is a continuous combustion engine, and the Lenoir, Otto, and most other gas engines are explosion engines?

A. Yes.

Q. What are the comparative merits of the two systems?

A. The continuous combustion engine is more steady and equable in its motion, and it does not require to be made so strong to generate a given power as an engine which has a high momentary pressure, and then subsides to a low pressure. It is contended, on the other hand, that the loss of heat through the water-jacket must be greater in an engine which has to maintain the temperature of combustion throughout the stroke than in an engine where the combustion is only momentary, and where, therefore, the average temperature within the cylinder will not be so high. There does not, however, seem to be much in this contention. The same quantity of heat has to be generated in either case, and if it be the fact that in explosive engines there is dissociation and afterwards recombination within the cylinder, there will be combustion throughout the stroke in either case, though in explosion engines there will be a greater inequality of temperature at different parts of the stroke.

Q. Then the dynamical efficacy of the two systems may be reckoned as about equal?

A. Yes; and the dynamical efficacy of equal weights of petroleum and coal gas may also be reckoned as about equal, or, in other words, one pound of petroleum properly applied will generate about as much heat—and, therefore, as much power—as 35½ cubic feet of coal gas.

Q. Will you give an example of the manner of computing the duty of an explosive gas engine?

A. For this purpose I will take the engine of which the diagram is given in fig. 209. A cubic foot of air at constant volume heated from the temperature of compression, 270·9° Fahr., to 2,766·6° Fahr., the temperature of explosion, requires an accession of heat equal to 24,416 foot-lbs. The maximum pressure is 220 lbs., the mean pressure 89·8 lbs., and the terminal pressure 49 lbs. per square inch. The temperature at the end of the stroke is 1715·4° Fahr. With these elements the work done by the piston should be equal to 7,888 foot-lbs. per cubic foot of combustible mixture. By a reference to the diagram and other data, it appears to have been 6,851 foot-lbs., as experimentally determined. But the proportion of gas present in a cubic foot of the explosive mixture is equal to 38,430 foot-lbs., of which only 6,851 have been expended in useful work. 11,253 foot-lbs. are lost through the exhaust, and the balance of 20,326 foot-lbs. has otherwise disappeared. Of this the greater part, or 52·89 per cent., is supposed to be lost through the water-jacket. But a part is no doubt lost from the non-combustion of a portion of the inflammable gas. This computation proceeds on the supposition that in a gas engine only as much gas is used to heat the mixture to the temperature of the explosion as should be theoretically sufficient; but, in point of fact, a considerably larger quantity of gas is required.

Q. What is the best maximum pressure in gas engines?

A. So far as theory is concerned, the higher the pressure in all engines the better the result which will be obtained. The question is one merely of prudence and safety. In some of Stirling's air engines the motive air has had a pressure of 1000 lbs. per square inch.

Q. Do you concur in the doctrine propounded at the Institution of Civil Engineers in 1882 by Sir C. W. Siemens, in regard to the structure of the gas engine of the future, to the effect that it would be an engine with a hot cylinder and with a regenerator?

A. No, I do not. A regenerator is too cumbrous an apparatus to be an acceptable addition; and a hot cylinder, if used without a regenerator, would dismiss the air at a wasteful temperature, and would not conduce to economy. The line of advance must be in a totally different direction, and the innovation when it comes will astonish by its obviousness and simplicity.

CHAPTER XII.

RULES, TABLES, AND MEMORANDA.

Q. Having now discussed the most important topics connected with the structure and operation of steam, air, and gas engines, it will be useful to recapitulate a few of the most prominent engineering data which require to be at hand in the performance of engineering calculations and in determining the most eligible forms of structure in the case of new machines. And first let me ask you what are the respective evaporative powers of different fuels in practice?

A. A pound of coal will evaporate 9 lbs. of water in ordinary boilers, and a pound of coke will evaporate about the same. Slack and dry oak have about half the evaporating power of coal, and ordinary pine a little over one-fourth. To evaporate a cubic foot per hour, there should be about 9 square feet of heating surface in land and marine boilers, and about 6 square feet in locomotives.

Q. How do you determine the quantity of water which will be sent into a boiler by an injector?

A. Multiply the diameter of the throat of the injector by 64, and square the product, which multiply by the square root of the pressure of the steam in atmospheres. The result is the gallons of water injected per hour.

Q. In casting iron, what allowance should be made for shrinkage?

A. That depends on the nature of the article. In pipes it is about ⅛th of an inch to the foot, but in girders and thick castings it is somewhat less. In thin brass castings it is about ⅛th to 9 inches. Cylinders reduce somewhat in diameter from contraction, and rather more at the bottom than the top if the bottom be cast on.

Q. What is the proper composition for rust joints?

A. 200 parts of iron borings, 2 of sal ammoniac, and 1 of flowers of sulphur. But rust joints are now seldom made.

Q. How is case-hardening by prussiate of potash accomplished?

A. Polish the articles and heat them to a bright red. Then rub the surfaces over with the salt, allow them to cool to a dull red, and immerse in water.

Q. Can glue be made so as to resist moisture?

A. Yes; such glue will be got by dissolving 1 lb. of cake glue in 2 quarts of skimmed milk.

Q. What is the composition of mortar and cement?

A. Mortar is composed of 1 part lime to 3 or 3½ of river sand. Hydraulic mortar is composed of 1 part of blue lias lime and 2½ parts of burnt clay, ground together. Concrete is made with 1 par of lime to 4 of gravel and 2 of sand.

Q. In warming a building by steam, what heating surface of pipe should be allowed?

A. About a square foot for every six square feet of window: and to permit good ventilation this quantity should be about doubled. Each person requires about 4 cubic feet of air per minute.

Q. What is the resistance of railway trains?

A. On straight lines, in good order, the resistances at 10, 15, 20 30, 40, 50, 60, and 70 miles per hour is about 8, 9, 10, 13, 17, 22, 29, and 36 lbs. per ton of train respectively.

Q. What is the quantity of gas required to maintain lights?

A. About 4 cubic feet per hour for indoor, and 5 for outdoor lights, the pressure being about 1 inch of water. A retort will generate about 3,000 cubic feet of gas in the 24 hours.

Q. What quantity of gas per hour will a given pipe transmit?

A. That depends not only on its diameter, but also on its length. If 1,350 times the square of the diameter be multiplied by the square root of the diameter divided by ·42 times the length in yards, the product will be the number of cubic feet of gas delivered per hour.

Q. What are the relative efficacies of different hydraulic motors?

A. Taking the whole theoretical power of the water as 1, the efficacy of an ordinary undershot wheel will be ·35, of Poncelet's undershot ·60, of the breast wheel ·55 to ·60, of an overshot wheel

·70 to ·80, of a turbine ·70, hydraulic ram ·60, and of a water pressure engine ·80.

Q. In windmills, should the velocity of the tips of the rotating sails be greater than that of the wind?

A. Yes; it should be about 2½ times greater. But windmills have now fallen into disuse, as small engines are found to do the work better.

ENGLISH WEIGHTS AND MEASURES.

IMPERIAL TROY WEIGHT.

Grains.		dwts.		oz.		lb.
24	=	1				
480	=	20	=	1		
5760	=	240	=	12	=	1

One cubic inch of distilled water at 62° Fahrenheit, the barometer being at 30 inches, weighs 252·458 troy grains. Troy weight means London weight, and is so called from the legend that London was founded by fugitives from Troy. It is chiefly used in weighing the precious metals, and for philosophical purposes.

APOTHECARIES' WEIGHT.

Grains.		scruple.		dram.		oz.		lb.
20	=	1						
60	=	3	=	1				
480	=	24	=	8	=	1		
5760	=	288	=	96	=	12	=	1

The weight of the ounce and the pound in apothecaries' weight are the same as in troy weight. Medicines are compounded by this weight, but drugs are bought and sold by avoirdupois weight.

IMPERIAL AVOIRDUPOIS WEIGHT.

Drams.		oz.		lb.		qr.		cwt.		ton.
16	=	1								
256	=	16	=	1						
7168	=	448	=	28	=	1				
28672	=	1792	=	112	=	4	=	1		
573440	=	35840	=	2240	=	80	=	20	=	1

The avoirdupois weight is that used in engineering computations, and for the general purposes of commerce. It was first introduced in the time of Henry VIII. for weighing butchers' meat; but it has gradually superseded all other weights for commercial purposes. The recognition of two different standards of weight with the same denominations of an ounce and pound, but weighing different quantities, is a serious inconvenience and anomaly, and in practice it leads to much confusion and misconception. The avoirdupois pound is greater than the troy pound in the proportion of 175 to 144, but the ounce avoirdupois is smaller than the troy ounce in the proportion of 437½ to 480. The dram in apothecaries' weight is 60 grains, while the dram in avoirdupois weight is $27\frac{11}{32}$ grains. The avoirdupois pound is 7,000 troy grains.

MEASURES OF LENGTH.

The unit of measure of the English linear system is the standard yard, which is divided into three feet, and each foot is subdivided into twelve inches. The oldest standard yard now in existence was constructed in the reign of Henry VII; but the standard yard usually referred to up to 1824 was a measure of rude construction, dating from the reign of Elizabeth. The multiples of the yard are the pole or perch, the furlong and the mile; but the pole and furlong are now little used. The relations of these several quantities are shown in the following table:—

Inches.	Feet.	Yards.	Poles.	Furlongs.	Miles.
1	0·083	0·028	0·00505	0·00012626	0·0000157828
12	1	0·333	0·06060	0·00151515	0·00018939
36	3	1	0·1818	0·004545	0·00056818
198	16·5	5·5	1	0·025	0·003125
7920	660	220	40	1	0·125
63,360	5280	1760	320	8	1

MEASURES OF SURFACE.

For measuring the area of any surface the square yard is subdivided into square feet and square inches—144 square inches being equal to a square foot, and 9 square feet to a square yard: 30¼ square yards are equal to a square pole, 40 square poles to a rood, and 4 roods to an acre, as shown more fully in the following table:—

Square Feet.	Square Yards.	Square Poles.	Roods.	Acres.
1	0·1111	0·00367309	0·000091827	0·000022957
9	1	0·0330579	0·000826448	0·000206612
272·25	30·25	1	0 025	0·00625
10890	1210	40	1	0·25
43560	4840	160	4	1

Very large surfaces, as the areas of countries, are expressed usually in square miles.

MEASURES OF CAPACITY.

Solids are measured by cubic yards, feet, and inches—1728 cubic inches making a cubic foot, and 27 cubic feet being a cubic yard. For liquids, corn, and other commodities susceptible of such measurement, the standard measure is the imperial gallon, which contains 277·274 cubic inches. A gallon of water at the temperature of 62 degrees, and with the barometer standing at 30 inches, weighs 10lbs. avoirdupois, and a cubic inch of water weighs 252·458 grains. The parts of a gallon are quarts and pints, 2 pints being 1 quart, and 4 quarts 1 gallon. The multiples of the gallon are the peck, the bushel, and the quarter—the peck being 2 gallons, the bushel 4 pecks, and the quarter 8 bushels. These relations are shown in the following table:—

Pints.	Quarts.	Gallons.	Pecks.	Bushels.	Quarters.
1	0·5	0·125	0·0625	0·015625	0·001953125
2	1	0·25	0·125	0·03125	0·00390625
8	4	1	0·5	0·125	0·015625
16	8	2	1	0·25	0·3125
64	32	8	4	1	0·125
512	256	64	32	8	1

In 1670. Mouton, of Lyons, proposed that the circumference of the earth should be divided into 600,000 parts, each of which should constitute a new geometrical foot which would be the basis of a metrical system, and he remarked that a pendulum of this length would make 3959¼th vibrations in half an hour. Huygens suggested the length of the seconds pendulum as a unit of length; and Condamine suggested that the unit should be the length of a pendulum vibrating seconds at the equator. No attempt, however, was made in practice to introduce a natural system, until the occurrence of the French revolution, when the present scientific system of weights and measures adopted in that country was first introduced. The basis of this system is the mètre, which is a ten millionth part of the quadrant, or fourth part of the earth's circumference. This length, deduced from the great trigonometrical measurement of the meridian from Dunkirk to Barcelona, is marked by two very fine lines, drawn at the temperature of melting ice, on a bar of platinum preserved in the archives of the Academy of Sciences at Paris; and by a careful comparison with the English standard yard, the length of the mètre is found to be 39 37079 English inches.

FRENCH WEIGHTS AND MEASURES.

The unit of the French system of weights is the gramme, which is the weight of the 100th part of a cubic mètre of distilled water, at the point of its maximum density, or 39 degrees Fahrenheit. A gramme is equal to 15·434 troy grains, and a kilogramme, consisting of 1000 grammes, is equal to 15,434 troy grains, or 2 lbs 3 oz. and 4,428 drams avoirdupois, or 2·2048 lbs. avoirdupois.

FRENCH WEIGHTS.

	Grammes.	Troy Grains.
Milligramme	·001	·01543
Centigramme	·01	·15434
Decigramme	·1	1·5434
Gramme.	1	15·434
Decagramme	10	154·34
Hectogramme	100	1543·4
Kilogramme	1000	15434
Myriagramme	10,000	154340

In Beardmore's Practical Tables a gramme is put down as equal to 15·428 grains, and a kilogramme as equal to 2·2055 lbs. avoirdupois. Now, as there are 7000 grains in a pound avoirdupois, 1 kilogramme should be equal to 15438·500 grains; and a gramme, being $\frac{1}{1000}$th of this, should be 15·438 grains. In Cresy's Dictionary the gramme is set down as 15·433 grains. In Brande's Dictionary it is set down as 15·434 grains; and this is the quantity followed in the above table, which, however, does not quite agree with the definitions we have given of the length of the mètre, and of the specific gravity of water. If we take the mètre at 39·370 inches, a tenth of a mètre is 3·937 inches, the cube of which is 61·023877953 cubic inches, which will therefore be, by this computation, the capacity of the litre; or, if we take the mètre at 39·371 inches, the capacity of the litre will be 61·025 cubic inches. A cubic inch of distilled water at 62° Fahr. weighs 252·458 grains, and at the maximum density 252·748 grains.

FRENCH MEASURES OF LENGTH.

	Metres.	English Inches.
Millimetre	0·001	0·03937
Centimetre	0·01	0·39370
Decimetre	0·1	3·93707
Metre.	1	39·37079
Hectometre.	100	3937·079
Kilometre	1000	39370·79
Myriametre.	10,000	393707·9

One square mètre is 1·196 square yards, or 10·764 square feet. One myriamètre is 6·2138 miles.

FRENCH MEASURES OF SURFACE.

	Square Metres.	English Measure.
Centiare . . .	1	
Are	100	1 are = 119·6 square yards, or 3·95 perches, or 0·0247 acres.
Hectare . . .	10,000	1 hectare = 2·471143 acres.

The unit of solid measure is the stere or cube of the mètre, which is equal to 35·31658 English cubic feet.

FRENCH MEASURES OF CAPACITY.

	Litres.	English Measure.
Centilitre. . .	0·01	
Decilitre . . .	0·1	A litre is the cube of one tenth part of a mètre
Litre	1	1 litre = 1·760773 pints, or 0·2200967 gallons, or 61·027 cubic inches, as usually reckoned; or more correctly 61·025 cubic inches.
Decalitre. . .	10	1 decalitre = 2·201 gallons.
Hectolitre . .	100	1 hectolitre = 22·01 gallons or 2·7512 bushels.
Kilolitre . . .	1000	

MISCELLANEOUS MEASURES, MULTIPLIERS, AND MEMORANDA.

MISCELLANEOUS MEASURES CONCERNING MEASURES OF LENGTH.

1 French line = 0·88815 inches.
1 French inch = 1·06578 „
1 French foot = 12·78 „
1 toise = 76·68 „
1 Irish mile = 2240 yards.
1 English mile = 1760 „
*1 geographical mile, or knot = 6101·333 feet.
3 geographical miles = 1 league.
7921 miles = diameter of the earth.
24856 miles = mean circumference of the earth.
39·01326 inches = length of seconds pendulum at the equator.

Wire gauge, No. 1 = 5-16ths of an inch; 4 = ¼; 7 = 3-16ths; 11 = 1-8th; 5 = 1-16th; 22 = 1-32nd.

TABLE OF MULTIPLIERS FOR TRANSFORMING BRITISH INTO FRENCH WEIGHTS AND MEASURES.

To change British	into French	Multiply by
Yards - - - - -	to mètres - - - -	0·914379
Miles - - - - - -	„ kilomètres - - -	1·609306
Acres - - - - - -	„ hectares - - - -	0·404667
Gallons - - - - -	„ litres - - - -	4·543389
Cubic inches - - -	„ „ - - - -	0·016386
Bushels - - - - -	„ hectolitres - - -	0·363471
Quarters - - - - -	„ „ - - -	2·907769
Troy grains - - -	„ grammes - - - -	0·064792
Troy pounds - - -	„ kilogrammes - - -	0·373202
Avoirdupois pounds - -	„ „ - - -	0·453554
To change French	**into British**	**Multiply by**
Mètres - - - -	to yards - - - -	1·093639
Kilomètres - - - - -	„ miles - - - -	0·621386
Hectares - - - - -	„ acres - - - -	2·471169
Litres - - - - -	„ gallons - - - -	0·220100
„ - - - -	„ cubic inches - - -	61·028028
Hectolitres - - - - -	„ bushels - - - -	2·751250
„ - - - - -	„ quarters - - - -	0·343906
Grammes - - - - -	„ troy grains - - -	15·434
Kilogrammes - - - -	„ troy pounds - - -	2·6795
„ - - - -	„ avoirdupois pounds -	2·204157

The value of a franc is 9·69 pence English.

CONCERNING MEASURES OF CAPACITY.

A cubic foot = 1728 cubic inches; 2200 cylindrical inches; 33,000 spherical inches; or 66,000 conical inches.

A gallon = 277·274 cubic inches.

A bushel = 2218·192 cubic inches.

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* The length of the English geographical mile is very variously stated by different authors. In Kelly's Universal Cambist it is stated to be equal to 2025 yards; whereas in Tate's Modern Cambist it is stated to be 1-60th part of a degree of the meridian, which, in the latitude of London, reduced to the level of the sea, is computed to be 69·146 statute miles, which makes the geographical mile 1·15243 statute miles, or 2028·2768 yards, or 6084·83 feet. In Weale's Pocket-book the length of a geographical or nautical mile is set down as 6082·66 feet; Haswell makes it 6075 feet; Bowditch, 6120 feet; Mrs. Somerville, in her Physical Geography, 6074·4 feet; and the French Nautical Almanac makes it 1852·183 mètres, or 6076·82818897 feet. The measurement we have taken is that given by Barlow, and adopted by Boulton and Watt. The Admiralty knot is 6080 feet.

MISCELLANEOUS MEASURES, MULTIPLIERS, AND MEMORANDA—*continued.*

A French tonne, or tonneau = 2204·787 lbs. avoirdupois = 1 cubic mètre of water. 1 lb. water contains 27·7 cubic inches, or 0·016 cubic ft.
The old wine gallon contained 231 cubic inches.
The old ale gallon contained 282 cubic inches.
The old corn bushel contained 2150·42 cubic inches.
A load of unhewn timber contains 40 cubic feet.
A load of squared timber contains 50 cubic feet.
A load of inch boards contains 600 square feet.
A load of bricks contains 500.
A load of lime contains 32 bushels.
A load of sand contains 36 bushels.
A bushel of wheat weighs about 60 lbs.
A bushel of flour weighs about 56 lbs.
A bushel of oats weighs about 40 lbs.
Area of a circle = diameter squared × ·7854.
A cubic foot of water weighs 62·4 lbs. avoirdupois.
A cubic inch of water weighs 0·03617 lb. avoirdupois.
A cubic foot of water = 6·25 imperial gallons.
1 cylindrical inch of water = ·02842 lb. avoirdupois.
1 cylindrical foot of water = 49·1 lbs. avoirdupois.
1 cylindrical foot of water = 5 imperial gallons.
1·8 cubic foot of water = 1 cwt.
35·84 cubic feet of water = 1 ton.
2·282 cylindrical feet of water = 1 cwt.
45·64 cylindrical feet of water = 1 ton.
11·2 imperial gallons of water = 1 cwt.
224 imperial gallons of water = 1 ton.
1 lb. air at 32° measures about 12½ cubic feet at atmospheric tension.
A gallon of water weighs 10 lbs. avoirdupois.
Each atmosphere of 14·7 lbs. per square inch = 33·9 feet of water.
Each lb. per square inch = 27·7 inches of water.
Each atmosphere of 14·7 lbs. per square inch = 29·92 inches of mercury.
Each lb. per square inch = 2·04 inches of mercury.

MISCELLANEOUS MULTIPLIERS.

Length of an arc = no. of deg. × rad. × ·01745.
Circum. of a circle = dia. × 3·1416.
Area of do. = dia.^{2} × ·7854.
Diameter of do. = cir. × ·31831.
Side of an equal square = dia. × ·8862.
Diameter of equal circle = $\sqrt{\text{area}}$ × 1·12837.
Ellipse, area = T. axis × C. axis × ·7854.
Sphere, surface = dia.^{2} × 3·1416.
Sphere, solidity = dia.^{3} × ·5236.
Square feet = circular inches × ·00456.
Square feet = square inches × ·00695.
Cubic feet = cubic inches × ·00058.
Cubic yards = cubic feet × ·03704.
Cubic yards = cylindrical feet × ·02909.
English miles = lineal ft. × ·00019, or lineal yds. × ·00058.
English acres = square yards × ·00026067.
Parabola, area = 2-3rds of base × height.
1 square foot = 183·346 circular inches.
Cubic inches in imp. gal. = 277·274.
Cubic foot = 6·232 imperial gals.

FRACTIONAL PARTS OF AN INCH AND FOOT EXPRESSED IN DECIMALS.

Parts of an inch.		Decimals	Parts of an inch.		Decimals	Parts of an inch.		Decimals of a foot.
$\frac{1}{32}$	=	·03125	$\frac{1}{2}$ & $\frac{1}{32}$	=	·53125	$\frac{1}{8}$	=	·01041
$\frac{1}{16}$	...	·0625	$\frac{1}{2}$ & $\frac{1}{16}$	...	·5625	$\frac{1}{4}$	...	·02083
$\frac{3}{32}$	...	·09375	$\frac{1}{2}$ & $\frac{3}{32}$	...	·59375	$\frac{3}{8}$	...	·03125
$\frac{1}{8}$	...	·125	$\frac{5}{8}$	...	·625	$\frac{1}{2}$	...	·04166
$\frac{1}{8}$ & $\frac{1}{32}$	...	·15625	$\frac{5}{8}$ & $\frac{1}{32}$	...	·65625	$\frac{5}{8}$	...	·0521
$\frac{1}{8}$ & $\frac{1}{16}$	...	·1875	$\frac{5}{8}$ & $\frac{1}{16}$	...	·6875	$\frac{3}{4}$	...	·0625
$\frac{1}{8}$ & $\frac{3}{32}$	...	·21875	$\frac{5}{8}$ & $\frac{3}{32}$	...	·71875	$\frac{7}{8}$	...	·07291
$\frac{1}{4}$	...	·25	$\frac{3}{4}$	...	·75	1	...	·0833
$\frac{1}{4}$ & $\frac{1}{32}$	...	·28125	$\frac{3}{4}$ & $\frac{1}{32}$	...	·78125	2	...	·1666
$\frac{1}{4}$ & $\frac{1}{16}$	...	·3125	$\frac{3}{4}$ & $\frac{1}{16}$	...	·8125	3	...	·25
$\frac{1}{4}$ & $\frac{3}{32}$	...	·34375	$\frac{3}{4}$ & $\frac{3}{32}$	...	·84375	4	...	·3333
$\frac{3}{8}$	...	·375	$\frac{7}{8}$	...	·875	5	...	·4166
$\frac{3}{8}$ & $\frac{1}{32}$	...	·40625	$\frac{7}{8}$ & $\frac{1}{32}$	...	·90625	6	...	·5
$\frac{3}{8}$ & $\frac{1}{16}$	...	·4375	$\frac{7}{8}$ & $\frac{1}{16}$	...	·9375	7	...	·5833
$\frac{3}{8}$ & $\frac{3}{32}$	...	·46875	$\frac{7}{8}$ & $\frac{3}{32}$	...	·96875	8	...	·6666
$\frac{1}{2}$	...	·5	1 inch	...	1·000	9	...	·75
						10	...	·8333
						11	...	·9166

ELASTICITY VOLUME AND TEMPERATURE OF STEAM.

From the experiments of M. Regnault.

Total Pressure per Square Inch.	Relative Volume.	Temperature.	Total Heat.	Weight of One Cubic Foot.	Total Pressure per Square Inch.	Relative Volume.	Temperature.	Total Heat.	Weight of One Cubic Foot.
Lbs.		*Fahr.*	*Fahr.*	*Lbs.*	*Lbs.*		*Fahr.*	*Fahr.*	*Lbs.*
15	1669	213·1	1178·9	·0373	36	745	260·9	1193·5	·0837
16	1572	216·3	1179·9	·0397	37	727	262·6	1194·0	·0858
17	1487	219·5	1180·9	·0419	38	709	264·2	1194·5	·0879
18	1410	222·5	1181·8	·0442	39	693	265·8	1195·0	·0900
19	1342	225·4	1182·7	·0465	40	677	267·3	1195·4	·0921
20	1280	228·0	1183·5	·0487	41	661	268·7	1195·9	·0942
21	1224	230·6	1184·3	·0510	42	647	270·2	1196·3	·0963
22	1172	233·1	1185·0	·0532	43	634	271·6	1196·8	·0983
23	1125	235·5	1185·7	·0554	44	621	273·0	1197·2	·1004
24	1082	237·9	1186·5	·0576	45	608	274·4	1197·6	·1025
25	1042	240·2	1187·2	·0598	46	595	275·8	1198·0	·1046
26	1005	242·3	1187·9	·0620	47	584	277·1	1198·4	·1067
27	971	244·4	1188·5	·0642	48	573	278·4	1198·8	·1087
28	939	246·4	1189·1	·0664	49	562	279·7	1199·2	·1108
29	909	248·4	1189·7	·0686	50	552	281·0	1199·6	·1129
30	881	250·4	1190·3	·0707	51	542	282·8	1200·0	·1150
31	855	252·2	1190·8	·0729	52	532	283·5	1200·4	·1171
32	830	254·1	1191·4	·0751	53	523	284·7	1200·8	·1192
33	807	255·9	1192·0	·0772	54	514	285·9	1201·1	·1212
34	785	257·6	1192·5	·0794	55	506	287·1	1201·5	·1232
35	765	259·3	1193·0	·0815	56	498	288·2	1201·8	·1252

EXPANSION OF DRY AIR BY HEAT.

[In the columns V. of the following table are expressed in cubic inches the volumes which a thousand cubic inches of air at 32° will have at the temperatures expressed in the columns T., the air being supposed to be maintained under the same pressure.]

T.	V.	T.	V.	T.	V.	T.	V.	T.	V.
—50	832·7	8	951·0	66	1069·4	124	1187·8	182	1306·1
—49	834·7	9	953·1	67	1071·4	125	1189·8	183	1308·2
—48	836·7	10	955·1	68	1073·5	126	1191·8	184	1310·2
—47	838·8	11	957·1	69	1075·5	127	1193·9	185	1312·2
46	840·8	12	959·2	70	1077·6	128	1195·9	186	1314·3
—45	842·8	13	961·2	71	1079·6	129	1198·0	187	1316·3
—44	844·9	14	963·3	72	1081·6	130	1200·0	188	1318·4
—43	846·9	15	965·3	73	1083·7	131	1202·0	189	1320·4
—42	849·0	16	967·3	74	1085·7	132	1204·1	190	1322·4
—41	851·0	17	969·4	75	1087·8	133	1206·1	191	1324·5
—40	853·1	18	971·4	76	1089·8	134	1208·2	192	1326·5
—39	855·1	19	973·5	77	1091·8	135	1210·2	193	1328·6
—38	857·1	20	975·5	78	1093·9	136	1212·2	194	1330·6
—37	859·2	21	977·6	79	1095·9	137	1214·3	195	1332·6
—36	861·2	22	979·6	80	1098·0	138	1216·3	196	1334·7
—35	863·3	23	981·6	81	1100·0	139	1218·4	197	1336·7
—34	865·3	24	983·7	82	1102·0	140	1220·4	198	1338·8
—33	867·3	25	985·7	83	1104·1	141	1222·4	199	1340·8
—32	869·4	26	987·8	84	1106·1	142	1224·5	200	1342·9
—31	871·4	27	989·8	85	1108·2	143	1226·5	201	1344·9
—30	873·5	28	991·8	86	1110·2	144	1228·6	202	1346·9
—29	875·5	29	993·9	87	1112·2	145	1230·6	203	1349·0
—28	877·6	30	995·9	88	1114·3	146	1232·7	204	1351·1
—27	879·6	31	998·0	89	1116·3	147	1234·7	205	1353·1
—26	881·6	32	1000·0	90	1118·4	148	1236·7	206	1355·1
—25	883·7	33	1002·0	91	1120·4	149	1238·8	207	1357·2
—24	885·7	34	1004·1	92	1122·4	150	1240·8	208	1359·2
—23	887·8	35	1006·1	93	1124·5	151	1242·9	209	1361·3
—22	889·8	36	1008·2	94	1126·5	152	1244·9	210	1363·3
—21	891·8	37	1010·2	95	1128·6	153	1246·9	211	1365·3
—20	893·9	38	1012·2	96	1130·6	154	1249·0	212	1367·4
—19	895·9	39	1014·3	97	1132·7	155	1251·0	213	1369·4
—18	898·0	40	1016·3	98	1134·7	156	1253·0	214	1371·5
—17	900·0	41	1018·4	99	1136·7	157	1255·1	215	1373·5
—16	902·0	42	1020·4	100	1138·8	158	1257·1	216	1375·5
—15	904·1	43	1022·4	101	1140·8	159	1259·2	217	1377·6
—14	906·1	44	1024·5	102	1142·9	160	1261·2	218	1379·6
—13	908·2	45	1026·5	103	1144·9	161	1263·3	219	1381·6
—12	910·2	46	1028·6	104	1147·0	162	1265·3	220	1383·7
—11	912·2	47	1030·6	105	1149·0	163	1267·3	230	1404·1
—10	914·3	48	1032·7	106	1151·0	164	1269·4	240	1424·5
— 9	916·3	49	1034·7	107	1153·1	165	1271·4	250	1444·9
— 8	918·4	50	1036·7	108	1155·1	166	1273·5	260	1465·3
— 7	920·4	51	1038·8	109	1157·1	167	1275·5	270	1485·7
— 6	922·5	52	1040·8	110	1159·2	168	1277·5	280	1506·1
— 5	924·5	53	1042·9	111	1161·2	169	1279·6	290	1526·5
— 4	926·5	54	1044·9	112	1163·3	170	1281·6	300	1546·9
— 3	928·6	55	1046·9	113	1165·3	171	1283·7	400	1751·0
— 2	930·6	56	1049·0	114	1167·3	172	1285·7	500	1955·1
- 1	932·7	57	1051·0	115	1169·4	173	1287·8	600	2159·2
0	934·7	58	1053·1	116	1171·4	174	1289·8	700	2363·3
1	936·7	59	1055·1	117	1173·5	175	1291·8	800	2567·3
2	938·8	60	1057·1	118	1175·5	176	1293·9	900	2771·4
3	940·8	61	1059·2	119	1177·6	177	1295·9	1000	2975·5
4	942·9	62	1061·2	120	1179·6	178	1298·0	1500	3997·9
5	944·9	63	1063·3	121	1181·6	179	1300·0	2000	5016·3
6	947·0	64	1065·3	122	1183·7	180	1302·0	2500	6036·7
7	949·0	65	1067·3	123	1185·7	181	1304·1	3000	7057·1

TABLE OF SPECIFIC GRAVITIES.

WATER AT 39·2°, FAHR., BEING 1.

[M. Regnault has ascertained that, under a pressure of 760 millims. or 29·9212 inches of mercury, a litre of water weighs 1000 grammes in the latitude of Paris. A litre of atmospheric air weighs 1·293187 grammes; so that water is 773·29 times heavier than air at a tension of 29·9212 inches of mercury. A cubic inch of distilled water at this tension, and at its point of maximum density, weighs 252·748 grains. A cubic inch of distilled water at the temperature of 62° Fahr., and with the barometer standing at 30 inches, weighs 252·458 grains.]

Metals.

	Specific gravity.	Weight of a cubic foot in pounds.	Weight of a cubic inch in ounces.
Aluminium - - - - - -	**2·600**	**162·19**	**1·502**
Antimony, fused - - - - -	6·742	420·59	3·894
„ native - - - - -	6·720	419·21	3·881
Arsenic, fused - - - - - -	8·310	518·41	4·800
„ native - - - - -	5·930	369·93	3·425
Bismuth, fused - - - - -	9·756	608·61	5·635
„ native - - - - -	9·570	597·01	5·528
Brass, wire - - - - - -	8·544	533·00	4·935
„ cast - - - - - -	8·399	523·96	4·851
Bronze - - - - - - -	**8·222**	**512·91**	**4·750**
Cadmium, hammered - - -	8·690	542·11	5·019
Cobalt, cast - - - - - -	7·811	487·27	4·520
Columbium - - - - - -	5·918	369·18	3·418
Copper, wrought - - - -	8·915	556·15	5·149
„ wire - - - - - -	8·878	553·84	5·127
„ cast - - - - - -	8·788	549·47	5·090
Gold, hammered - - - - -	19·362	1207·87	11·184
„ cast - - - - - -	19·260	1201·50	11·125
„ pure - - - - - -	19·258	1201·38	11·124
„ English standard, 22 carats, fine fused, not hammered -	**18·888**	**1178·30**	**10·910**
Gun-metal - - - - - -	8·784	547·97	5·074
Iridium, ore of - - - - - -	19·500	1216·47	11·263
„ cast by electric battery - -	18·680	1165·32	10·790
Iron, wrought - - - - - -	7·758	483·84	4·480
„ cast - - - - - -	7·093	442·36	4·097
Lead, English cast - - - - -	11·446	714·04	6·611
„ milled sheet - - - - -	11·407	711·61	6·589
„ wiredrawn - - - - -	11·317	705·99	6·537
Manganese - - - - - -	8·010	497·19	4·627
Mercury, at 32° Fahr. - - -	***13·619**	**849·60**	**7·866**
„ 60° „ - - -	13·580	847·17	7·844
Molybdenum, saturated with water -	7·500	467·87	4·331
„ native - - - - -	4·667	291·14	2·696
Nickel, forged - - - - - -	8·666	540·61	5·006
„ cast - - - - - -	8·279	516·47	4·782

TABLE OF SPECIFIC GRAVITIES—Metals—*continued.*

	Specific gravity.	Weight of a cubic foot in pounds.	Weight of a cubic inch in ounces.
Palladinm	11·300	704·93	6·527
Platinum, rolled	22·060	1376·18	12·742
„ ?	21·530	1343·08	12·436
Potassium	·865	53 96	·500
Rhodium	**11·000**	**686·22**	**6·354**
Silver	10·470	653·15	6·048
Sodium	·972	60·64	·561
Steel, hammered	7·840	489·08	4·528
„ not hammered	7·810	487·21	4 511
Tantalium metal	5·610	349·97	3·240
Tellurium	6·240	389 27	3·604
Tin	7·291	454 84	4·211
Tungsten	17·600	1097·95	10·166
Uranium	9 000	561·45	5·199
Wolfram	**7·300**	**455·40**	**4·217**
Zinc	7·190	448·54	4·153
Stones, &c.			
Alabaster	**2·699**	**168·37**	**1·559**
Basalt	2·650	165·31	1·532
Brick	1·557 2·168	97·13 135·25	·899 1·252
Brickwork, in cement	1·680	104·80	·970
„ mortar	1·568	97·81	·906
Building stone	1·800	112 29	1·040
Cement, Portland	1 280	79·85	·900
„ Roman	1 040	64·88	·601
Chalk	**2·767**	**172·61**	**1·598**
Concrete, Portland cement	2·272	141 73	1·315
„ common lime	1·900	118·53	1·097
Clay, common	2·000	124·76	1·155
„ Medway	1 440	89·21	·832
Cutler's stone	2 111	131·69	1 219
Earth, rammed	1·584	98·81	·915
Flint	2·600	162·19	1·502
„ millstone	2·480	154·71	1·432
Freestone	2·520	157·21	1·456
Glass, English flint	**3·330**	**207·73**	**1·923**
„ St. Gobain, of	2·380	160·37	1·375
Granite	2·700	168·43	1·559
Gravel	1 900	118·53	1 097
Grindstone	2·412	150·47	1·393
Limestone	2·939	183·34	1·657
Marble	2·720	169·68	1·455
Marl	1·600 2·800	99·81 174·67	·924 1·617
Millstone	2·480	154·71	1·432

TABLE OF SPECIFIC GRAVITIES—Stones, &c.—*continued.*

	Specific gravity.	Weight of a cubic foot in pounds.	Weight of a cubic inch in ounces.
Mortar	**1·751**	**109·23**	**1·011**
Oolite, Portland	2·145	133·81	1·239
„ Bath	1·839	114·72	1·062
Pavingstone	2·415	150·66	1·395
Peat, hard	1·329	82·91	·768
Plaster, stone	2·200	137·24	1·271
Porphyry	2·700	168·43	1·559
Portland stone	2·570	160·32	1·484
Pozzolano	1·444	90·08	·830
Pumice stone	·915	57·08	·529
Purbeck	**2·601**	**162·26**	**1·502**
Ragstone	2·470	154·09	1·427
Roofing	1·886	117·09	1·090
Rotten stone	1·981	123·58	1·144
Sand, river	1·886	117·09	1·090
Sandstone	2·430	151·59	1·404
Slate	2·832	176·66	1·636
„ common	2·671	166·63	1·543
Stone, common	2·520	157·21	1·456
Sulphur, native	2·033	126·82	1·174
„ melted	**1·991**	**124·20**	**1·150**
Tile	1·815	113·22	1·048

Woods.

	Specific gravity.	Weight of a cubic foot in pounds.	Weight of a cubic inch in ounces.
Acacia	**·705**	**43·98**	**·407**
Alder	·800	49·91	·462
Apple tree	·733	45·73	·423
Ash	·845	52·71	·488
Bay tree, Spanish	·822	51·28	·475
Beech	·777	48·47	·449
Birch, common	·792	49·41	·457
„ American black	·648	40·42	·374
Boxwood, Dutch	1·320	82·35	·762
„ dry	**1·030**	**64·25**	**·595**
„ French	·910	56·77	·526
Brazil wood, red	1·031	64·31	·596
Cedar, Indian	1·315	82·34	·759
„ American	·561	35·00	·324
Cherry tree	·715	44·60	·413
Citron	·726	45·28	·419
Cocoa wood	1·040	64·88	·601
Cork tree	·240	14·97	·139
Cypress	·598	37·30	·345
Deal, Christiana	**·681**	**42·48**	**·393**
„ Memel	·390	24·33	·225

TABLE OF SPECIFIC GRAVITIES—Woods—*continued.*

	Specific gravity.	Weight of a cubic foot in pounds.	Weight of a cubic inch in ounces.
Ebony, American	1·331	83·03	·769
„ Indian	1·209	75·42	·698
Elder	·695	43·29	·401
Elm	·671	41·84	·388
Filbert	·600	37·43	·346
Fir	·524	32·69	·303
„ Riga	·750	46·79	·433
Hazel	·606	37·80	·350
Lancewood	1·022	63·75	·590
Larch, seasoned	·522	32·56	·301
Lignum Vitæ	1·330	82·97	·768
Logwood	·913	56·95	·527
Mahogany, Spanish	·800	49·91	·462
„ Honduras	·560	34·93	·323
Norway spars	·580	36·18	338
Oak, English	·934	58·26	·539
„ Canadian	·872	54·40	·504
„ Dantzic	·756	47·16	·437
Pear tree	·650	40·55	·375
Pine, pitch	·660	41·17	·381
„ red	·657	40·98	·379
„ yellow	·461	28·76	·266
Plane tree	·640	39·80	·370
Poplar	·383	23·89	·221
Sycamore	·690	43·04	·398
Teak, dry	·657	40·98	·379
Walnut	·671	41·84	·388
Willow, dry	·390	24·33	·225
Yew, Dutch	·788	49·16	·455
„ Spanish	·807	50·34	·466

Liquids.

	Specific gravity.	Weight of a cubic foot in pounds.
Acid, sulphuric, concentrated	1·841	114·85
„ fuming azotic	1·451	90·53
„ hypo-azotic	1·451	90·53
„ hyposulphuric	1·347	84·09
„ azotic, of commerce	1·222	76·23
„ hydrochloric, concentrated	1·208	75·36
„ muriatic	1·194	74·48
„ acetic, greatest density	1·079	67·31
„ „ monohydrate	1·068	66·62

TABLE OF SPECIFIC GRAVITIES—Liquids—*continued*

	Specific gravity.	Weight of a cubic foot in pounds.
Acid, oleic	·898	56·02
Acetone	·792	49·41
Alcohol, greatest density	·927	57·83
„ commercial	·837	52·21
„ absolute	·797	49·72
Ammoniac	·897	55·96
Beer	1·028	64·13
Bromine	2·996	186·90
Cyder	1·018	63·50
Esprit de bois	·798	49·78
Ether, hydrochloric	·874	54·52
„ acetic	·868	54·15
„ ?	·715	44·60
Essence of bitter almonds	1·043	65·06
„ cinnamon	1·010	63·01
„ cumin	·969	60·45
Mercaptan	·840	52·40
Milk	1·032	64·38
Naphtha	·847	52·84
Oil of sperica	1·193	73·17
„ cinnamon	1·044	65 13
„ aniseed	·987	61·57
„ linseed	·940	58·64
„ whale	·923	57·58
„ olive	·915	57·08
„ lavender	·894	55·77
„ sperm	·872	54·40
„ turpentine	·870	54·28
„ potato	·818	51 03
Sulphur, protochloride of	1·680	104·80
Sulphuret of carbon	1·263	78·79
Vinegar	1·010	63·01
Water, from the Dead Sea	1·240	77 35
„ „ Mediterranean	1 029	64·18
„ „ Irish Channel	1·028	64·13
„ „ Baltic	1·015	63·32
„ distilled	1·000	62·38
Wine, Madeira	1·038	64·75
„ champagne	·998	62·26
„ port	·997	62·19
„ Bordeaux	·994	62·01
„ Burgundy	·991	61·82

TABLE OF SPECIFIC GRAVITIES—*continued.*

Gases.

Temperature, 32° Fahr.; barometer standing at 30 inches, and the weight of air being unity.

[Air at the mean pressure of the atmosphere, or 29·9212 inches of mercury, and at the freezing point, has, according to M. Regnault, a specific gravity of 1·293187 as compared with water reckoned as 1000, and the bulks being inversely as the specific gravities, it follows that air is 773·29 times the bulk of an equal weight of water.]

If the specific gravity of water be taken at 1000, air at 32° and with a tension of 30 inches of mercury is commonly reckoned as having a specific gravity of 0·628, and a cubic foot will then weigh 1·291 ounces.*	Specific gravity.	Weight of a cubic foot in ounces.
GASES :—		
Acetone - - - - - - -	2·019	2·606
Acid, nitrous - - - - - -	2·658	3·431
„ sulphurous - - - - - -	2·234	2 884
„ muriatic - - - - - -	1·534	1·980
„ carbonic - - - - - -	1·529	1·973
„ sulphohydric - - - -	1·191	1·537
Ammonia - - - - - - -	0·590	·761
Chlorine - - - - - - -	**2·470**	**3·188**
Cyanogen - - - - - - -	1·805	2 330
Hydrogen - - - - - - -	0·069	0 089
„ carburetted - - - -	0·555	0·716
„ bicarburetted, or olefiant gas -	0·972	1 254
Nitrogen - - - - - - -	0·972	1·254
Oxide, nitrous - - - - - -	1·527	1·971
„ nitric - - - - - -	1·011	1·305
„ carbonic - - - - - -	0·927	1·197
Oxygen - - - - - - -	1·106	1·427

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* This specific gravity does not exactly agree with that involved in the relative volumes of steam and water as determined by M. Regnault; but the deviation is not wider than is to be expected in any strict comparison of such determinations. If a cubic foot of water weigh 62·38 lbs., or 998·08 oz., then, if the relative bulk of saturated steam at 15 lbs. pressure be 1669 to 1, a cubic foot of such steam must weigh $\frac{1}{1669}$th part of 998·08 oz., or 0·5[illegible] oz. at a temperature of 212° Fahr. But it appears by M. Regnault's experiments, referred to in page 68, that a gas or vapour expands about 0·3665th of its bulk in being raised from the freezing to the boiling point. Hence, 1000 measures of air at 32° will expand to 1366·5 measures, or 1366·5 measures in being cooled from 212° to 32° Fahr., will contract from 1366·5 measures to 1000. If we suppose that steam could be similarly cooled without condensation, the specific gravity of the cooled steam would be greater than that of the heated steam in the proportion of 1366·5 to 1000, and $\frac{1366{\cdot}5 \times {\cdot}59}{1000}$ will represent the weight of a cubic foot of the cooled steam = ·806 oz. The weight of a cubic foot of air is set down at 1·291 oz. at the temperature of 32°, and the weight of a cubic foot of steam at 32° being set down as ·623 of this amount will be ·804 oz., which does not differ much from the previous determination.

TABLE OF CIRCUMFERENCES AND AREAS OF CIRCLES.

Diam. in Inches.	Circum.	Area	Side of equal Square.	Diam in inches.	Circum.	Area.	Side of equal Square.
⅛	**·3927**	**·0122**	**·1167**	⅜	20·027	31·919	5·6495
¼	·7854	·0490	·2115	½	20·420	33·183	4·7603
⅜	1·1781	·1104	·3223	⅝	20·813	34·471	5·8711
½	1·5708	·1963	·4331	¾	21·205	35·784	5·9819
⅝	1·9635	·3068	·5438	⅞	21·598	37·122	6·0927
¾	2·3562	·4417	·6646	**7**	**21·991**	**38·484**	**6·2034**
⅞	2·7489	·6013	·7754	⅛	22·383	39·871	6·3142
1	**3·1416**	**·7854**	**·8862**	¼	22·776	41·282	6·4250
⅛	3·5343	·9940	·9969	⅜	23·169	42·718	6·5358
¼	3·9270	1·2271	1·0775	½	23·562	44·178	6·6465
⅜	4·3197	1·4848	1·2185	⅝	23·954	45·663	6·7573
½	4·7124	1·7671	1·3293	¾	24·347	47·173	6·8681
⅝	5·1051	2·0739	1·4401	⅞	24·740	48·707	6·9789
¾	5·4978	2·4052	1·5508	**8**	**25·132**	**50·265**	**7·0897**
⅞	5·8905	2·7611	1·6616	⅛	25·515	51·848	7·2005
2	**6·2832**	**3·1416**	**1·7724**	¼	25·918	53·456	7·3112
⅛	6·6759	3·5465	1·8831	⅜	26·310	55·088	7·4220
¼	7·0686	3·9760	1·9939	½	26·703	56·745	7·5328
⅜	7·4613	4·4302	2·1047	⅝	27·096	58·426	7·6436
½	7·8540	4·9087	2·2155	¾	27·489	60·132	7·7544
⅝	8·2467	5·4119	2·3262	⅞	27·881	61·862	7·8651
¾	8·6394	5·9395	2·4370	**9**	**28·274**	**63·617**	**7·9760**
⅞	9·0321	6·4918	2·5478	⅛	28·667	65·396	8·0866
3	**9·4248**	**7·0686**	**2·6586**	¼	29·059	67·200	8·1974
⅛	9·8175	7·6699	2·7694	⅜	29·452	69·029	8·3081
¼	10·210	8·2957	2·8801	½	29·845	70·882	8·4190
⅜	10·602	8·9462	2·9909	⅝	30·237	72·759	8·5297
½	10·995	9·6211	3·1017	¾	30·630	74·662	8·6403
⅝	11·388	10·320	3·2124	⅞	31·023	76·588	8·7513
¾	11·781	11·044	3·3232	**10**	**31·416**	**78·540**	**8·8620**
⅞	12·173	11·793	3·4340	⅛	31·808	80·515	8·9728
4	**12·566**	**12·566**	**3·5448**	¼	32·201	82·516	9·0836
⅛	12·959	13·364	3·6555	⅜	32·594	84·540	9·1943
¼	13·351	14·186	3·7663	½	32·986	86·590	9·3051
⅜	13·744	15·033	3·8771	⅝	33·379	88·664	9·4159
½	14·137	15·904	3·9880	¾	33·772	90·762	9·5267
⅝	14·529	16·800	4·0987	⅞	34·164	92·885	9·6375
¾	14·922	17·720	4·2095	**11**	**34·557**	**95·033**	**9·7482**
⅞	15·315	18·665	4·3202	⅛	34·950	97·205	9·8590
5	**15·708**	**19·635**	**4·4310**	¼	35·343	99·402	9·9698
⅛	16·100	20·629	4·5417	⅜	35·735	101·623	10·080
¼	16·493	21·647	4·6525	½	36·128	103·869	10·191
⅜	16·886	22·690	4·7633	⅝	36·521	106·139	10·302
½	17·278	23·758	4·8741	¾	36·913	108·434	10·413
⅝	17·671	24·850	4·9848	⅞	37·306	110·753	10·523
¾	18·064	25·967	5·0956	**12**	**37·699**	**113·097**	**10·634**
⅞	18·457	27·108	5·2064	⅛	38·091	115·466	10·745
6	**18·849**	**28·274**	**5·3172**	¼	38·484	117·859	10·856
⅛	19·242	29·464	5·4280	⅜	38·877	120·276	10·966
¼	19·635	30·679	5·5388	½	39·270	122·718	11·077

TABLE OF CIRCUMFERENCES AND AREAS OF CIRCLES—*continued.*

Diam. in Inches.	Circum.	Area.	Side of equal Square.	Diam in Inches.	Circum.	Area.	Side of equal Square.
⅝	39·662	125·184	11·188	⅞	59·297	279·811	16·727
¾	40·055	127·676	11·299	**19**	**59·690**	**283·529**	**16·837**
⅞	40·448	130·192	11·409	⅛	60·083	287·272	16·948
13	**40·840**	**132·732**	**11·520**	¼	60·475	291·039	17·060
⅛	41·233	135·297	11·631	⅜	60·868	294·831	17·170
¼	41·626	137·886	11·742	½	61·261	298·648	17·280
⅜	42·018	140·500	11·853	⅝	61·653	302·489	17·391
½	42·411	143·139	11·963	¾	62·046	306·355	17·502
⅝	42·804	145·802	12·074	⅞	62·439	310·245	17·613
¾	43·197	148·489	12·185	**20**	**62·832**	**314·160**	**17·724**
⅞	43·589	151·201	12·296	⅛	63·224	318·099	17·834
14	**43·982**	**153·938**	**12·406**	¼	63·617	322·063	17·945
⅛	44·375	156·699	12·517	⅜	64·010	326·051	18·056
¼	44·767	159·485	12·628	½	64·402	330·064	18·167
⅜	45·160	162·295	12·739	⅝	64·795	334·101	18·277
½	45·553	165·130	12·850	¾	65·188	338·163	18·388
⅝	45·945	167·989	12·960	⅞	65·580	342·250	18·499
¾	46·338	170·873	13·071	**21**	**65·793**	**346·361**	**18·610**
⅞	46·731	173·782	13·182	⅛	66·366	350·497	18·721
15	**47·124**	**176·715**	**13·293**	¼	66·759	354·657	18·831
⅛	47·516	179·672	13·403	⅜	67·151	358·841	18·942
¼	47·909	182·654	13·541	½	67·544	363·051	19·053
⅜	48·302	185·661	13·625	⅝	67·937	367·284	19·164
½	48·694	188·692	13·736	¾	68·329	371·543	19·274
⅝	49·087	191·748	13·847	⅞	68·772	375·826	19·385
¾	49·480	194·828	13·957	**22**	**69·115**	**380·133**	**19·496**
⅞	49·872	197·933	14·068	⅛	69·507	384·465	19·607
16	**50·265**	**201·062**	**14·179**	¼	69·900	388·822	19·718
⅛	50·658	204·216	14·290	⅜	70·293	393·203	19·828
¼	51·051	207·394	14·400	½	70·686	397·608	19·939
⅜	51·443	210·597	14·511	⅝	71·078	402·038	20·050
½	51·836	213·825	14·622	¾	71·471	406·493	20·161
⅝	52·229	217·077	14·732	⅞	71·864	410·972	20·271
¾	52·621	220·353	14·843	**23**	**72·256**	**415·476**	**20·382**
⅞	53·014	223·654	14·954	⅛	72·649	420·004	20·493
17	**53·407**	**226·980**	**15·065**	¼	73·042	424·557	20·604
⅛	53·799	230·330	15·176	⅜	73·434	429·135	20·715
¼	54·192	233·705	15·286	½	73·827	433·731	20·825
⅜	54·585	237·104	15·397	⅝	74·220	438·363	20·956
½	54·978	240·528	15·508	¾	74·613	443·014	21·047
⅝	55·370	243·977	15·619	⅞	75·005	447·699	21·158
¾	55·763	247·450	15·730	**24**	**75·398**	**452·390**	**21·268**
⅞	56·156	250·947	15·840	⅛	75·791	457·115	21·379
18	**56·548**	**254·469**	**15·951**	¼	76·183	461·864	21·490
⅛	56·941	258·016	16·062	⅜	76·576	466·638	21·601
¼	57·334	261·587	16·173	½	76·969	471·436	21·712
⅜	57·726	265·182	16·283	⅝	77·361	476·259	21·822
½	58·119	268·803	16·394	¾	77·754	481·106	21·933
⅝	58·512	272·447	16·505	⅞	78·147	485·978	22·044
¾	58·905	276·117	16·616	**25**	**78·540**	**490·875**	**22·155**

TABLE OF CIRCUMFERENCES AND AREAS OF CIRCLES—*continued.*

Diam. in Inches.	Circum.	Area.	Side of equal Square.	Diam. in Inches.	Circum.	Area.	Side of equal Square.
⅛	78·932	495·796	22·265	⅜	98·567	773·140	27·804
¼	79·325	500·741	22·376	½	98·968	779·313	27·915
⅜	79·718	505·711	22·487	⅝	99·353	785·510	28·026
½	80·110	510·706	22·598	¾	99·745	791·732	28·136
⅝	80·503	515·725	22·709	⅞	100·138	797·978	28·247
¾	80·896	520·769	22·819	**32**	**100·531**	**804·249**	**28·358**
⅞	81·288	525·837	22·930	⅛	100·924	810·545	28·469
26	**81·681**	**530·930**	**23·041**	¼	101·316	816·865	28·580
⅛	82·074	536·047	23·152	⅜	101·709	823·209	28·691
¼	82·467	541·189	23·062	½	102·102	829·578	28·801
⅜	82·859	546·356	23·373	⅝	102·494	835·972	28·912
½	83·252	551·547	23·484	¾	102·887	842·390	29·023
⅝	83·645	556·762	23·595	⅞	103·280	848·833	29·133
¾	84·037	562·002	23·708	**33**	**103·672**	**855·30**	**29·244**
⅞	84·430	567·267	23·816	⅛	104·055	861·79	29·355
27	**84·823**	**572·556**	**23·927**	¼	104·458	868·30	29·466
⅛	85·215	577·870	24·038	⅜	104·850	874·84	29·577
¼	85·608	583·208	24·149	½	105·243	881·41	29·687
⅜	86·001	588·571	24·259	⅝	105·636	888·00	29·798
½	86·394	593·958	24·370	¾	106·029	894·61	29·909
⅝	86·786	599·370	24·481	⅞	106·421	901·25	30·020
¾	87·179	604·807	24·592	**34**	**106·814**	**907·92**	**30·131**
⅞	87·572	610·268	24·703	⅛	107·207	914·61	30·241
28	**87·964**	**615·753**	**24·813**	¼	107·599	921·32	30·352
⅛	88·357	621·263	24·924	⅜	107·992	928·06	30·463
¼	88·750	626·798	25·035	½	108·385	934·82	30·574
⅜	89·142	632·357	25·146	⅝	108·777	941·60	30·684
½	89·535	637·941	25·256	¾	109·170	948·41	30·795
⅝	89·928	643·594	25·367	⅞	109·563	955·25	30·906
¾	90·321	649·182	25·478	**35**	**109·956**	**962·11**	**31·017**
⅞	90·713	654·839	25·589	⅛	110·348	968·99	31·128
29	**91·106**	**650·521**	**25·699**	¼	110·741	975·90	31·238
⅛	91·499	666·227	25·8 0	⅜	111·134	982·84	31·349
¼	91·891	671·958	25·921	½	111·526	989·80	31·460
⅜	92·284	677·714	26·032	⅝	111·919	996·78	31·571
½	92·677	683·494	26·143	¾	112·312	1003·79	31·681
⅝	93·069	689·298	26·253	⅞	112·704	1010·83	31·792
¾	93·462	695·128	26·364	**36**	**113·097**	**1017·87**	**31·903**
⅞	93·855	700·981	26·478	⅛	113·490	1024·95	32·014
30	**94·248**	**706·860**	**26·586**	¼	113·883	1032·06	32·124
⅛	94·640	712·762	26·696	⅜	114·275	1039·19	32·235
¼	95·033	718·690	26·807	½	114·668	1046·39	32·346
⅜	95·426	724·641	26·918	⅝	115·061	1053·52	32·457
½	95·818	730·618	27·029	¾	115·453	1060·78	32.567
⅝	96·211	736·619	27·139	⅞	115·846	1067·95	32·678
¾	96·604	742·644	27·250	**37**	**116·239**	**1075·21**	**32·769**
⅞	96·996	748·694	27·361	⅛	116·631	1082·48	32·900
31	**97·389**	**754·769**	**27·472**	¼	117·024	1089·79	33·011
⅛	97·782	760·868	27·583	⅜	117·417	1097·11	33·021
¼	98·175	766·992	27·693	½	117·810	1104·46	33·232

TABLE OF CIRCUMFERENCES AND AREAS OF CIRCLES—*continued.*

Diam. in Inches.	Circum.	Area.	Side of equal Square.	Diam. in Inches.	Circum.	Area.	Side of equal Square.
⅝	118·202	1111·84	33·343	⅞	137·837	1511·90	38·882
¾	118·595	1119·24	33·454	**44**	**138·230**	**1520·53**	**38·993**
⅞	118·988	1126·66	33·564	⅛	138·623	1529·18	39·103
38	**119·380**	**1134·11**	**33·675**	¼	139·015	1537·86	39·214
⅛	119·773	1141·59	33·786	⅜	139·408	1546·55	39·325
¼	120·166	1149·08	33·897	½	139·801	1555·28	39·436
⅜	120·558	1156·61	34·008	⅝	140·193	1564·03	39·546
½	120·951	1164·15	34·118	¾	140·586	1572·81	39·657
⅝	121·344	1171·73	34·229	⅞	140·979	1581·61	39·768
¾	121·737	1179·32	34·340	**45**	**141·372**	**1590·43**	**39·879**
⅞	122·129	1186·94	34·451	⅛	141·764	1599·28	39·989
39	**122·522**	**1194·59**	**34·561**	¼	142·157	1608·15	40·110
⅛	122·915	1202·26	34·672	⅜	142·550	1617·04	40·211
¼	123·307	1209·95	34·783	½	142·942	1625·97	40·322
⅜	123·700	1217·67	34·894	⅝	143·335	1634·92	40·432
½	124·093	1225·42	35·005	¾	143·728	1643·89	40·543
⅝	124·485	1233·18	35·115	⅞	144·120	1652·88	40·654
¾	124·878	1240·98	35·226	**46**	**144·513**	**1661·90**	**40·765**
⅞	125·271	1248·79	35·337	⅛	144·906	1670·95	40·876
40	**125·664**	**1256·64**	**35·448**	¼	145·299	1680·01	40·986
⅛	126·056	1264·50	35·558	⅜	145·691	1689·10	41·097
¼	126·449	1272·39	35·669	½	146·084	1698·23	41·208
⅜	126·842	1280·31	35·780	⅝	146·477	1707·37	41·319
½	127·234	1288·25	35·891	¾	146·869	1716·54	41·429
⅝	127·627	1296·21	36·002	⅞	147·262	1725·73	41·540
¾	128·020	1304·20	36·112	**47**	**147·655**	**1734·94**	**41·651**
⅞	128·412	1312·21	36·223	⅛	148·047	1744·18	41·762
41	**128·805**	**1320·25**	**36·334**	¼	148·440	1753·45	41·873
⅛	129·198	1328·32	36·445	⅜	148·833	1762·73	41·983
¼	129·591	1336·40	36·555	½	149·226	1772·05	42·094
⅜	129·983	1344·51	36·666	⅝	149·618	1781·39	42·205
½	130·376	1352·65	36·777	¾	150·011	1790·76	42·316
⅝	130·769	1360·81	36·881	⅞	150·404	1800·14	42·427
¾	131·161	1369·00	36·999	**48**	**150·796**	**1809·56**	**42·537**
⅞	131·554	1377·21	37·109	⅛	151·189	1818·99	42·648
42	**131·947**	**1385·44**	**37·220**	¼	151·582	1828·46	42·759
⅛	132·339	1393·70	37·331	⅜	151·974	1837·96	42·870
¼	132·732	1401·98	37·442	½	152·367	1847·45	42·980
⅜	133·125	1410·29	37·552	⅝	152·760	1856·99	43·091
½	133·518	1418·62	37·663	¾	153·153	1866·55	43·202
⅝	133·910	1426·98	37·774	⅞	153·545	1876·13	43·313
¾	134·303	1435·36	37·885	**49**	**153·938**	**1885·74**	**43·423**
⅞	134·696	1443·77	37·996	⅛	154·331	1895·37	43·534
43	**135·088**	**1452·20**	**38·106**	¼	154·723	1905·03	43·645
⅛	135·481	1460·65	38·217	⅜	155·116	1914·70	43·756
¼	135·874	1469·13	38·328	½	155·509	1924·42	43·867
⅜	136·266	1477·63	38·439	⅝	155·901	1934·15	43·977
½	136·659	1486·17	38·549	¾	156·294	1943·91	44·088
⅝	137·052	1494·72	38·660	⅞	156·687	1953·69	44·199
¾	137·445	1503·30	38·771	**50**	**157·080**	**1963·50**	**44·310**

TABLE OF CIRCUMFERENCES AND AREAS OF CIRCLES—*continued.*

Diam. in Inches.	Circum.	Area.	Side of equal Square.	Diam. in Inches.	Circum.	Area.	Side of equal Square.
¼	157·865	1983·18	44·531	¾	197·135	3092·56	55·609
½	158·650	2002·96	44·753	**63**	**197·920**	**3117·25**	**55·830**
¾	159·436	2022·84	44·974	¼	198·706	3142·04	56·052
51	**160·221**	**2042·82**	**45·196**	½	199·491	3166·92	56·273
¼	161·007	2062·90	45·417	¾	200·277	3191·91	56·495
½	161·792	2083·07	45·639	**64**	**201·062**	**3216·99**	**56·716**
¾	162·577	2103·35	45·861	¼	201·847	3242·17	56·938
52	**163·363**	**2123·72**	**46·082**	½	202·633	3267·46	57·159
¼	164·148	2144·19	46·304	¾	203·418	3292·83	57·381
½	164·934	2164·75	46·525	**65**	**204·204**	**3318·31**	**57·603**
¾	165·719	2185·42	46·747	¼	204·989	3343·88	57·824
53	**166·504**	**2206·18**	**46·968**	½	205·774	3369·56	58·046
¼	167·290	2227·05	47·190	¾	206·560	3395·33	58·267
½	168·075	2248·01	47·411	**66**	**207·345**	**3421·20**	**58·469**
¾	168·861	2269·06	47·633	¼	208·131	3447·16	58·710
54	**169·646**	**2290·22**	**47·854**	½	208·916	3473·23	58·932
¼	170·431	2311·48	48·076	¾	209·701	3499·39	59·154
½	171·217	2332·83	48·298	**67**	**210·487**	**3525·66**	**59·375**
¾	172·002	2354·28	48·519	¼	211·272	3552·01	59·597
55	**172·788**	**2375·83**	**48·741**	½	212·058	3578·47	59·818
¼	173·573	2397·48	48·962	¾	212·843	3605·03	60·040
½	174·358	2419·22	49·184	**68**	**213·628**	**3631·68**	**60·261**
¾	175·144	2441·07	49·405	¼	214·414	3658·44	60·483
56	**175·929**	**2463·01**	**49·627**	½	215·199	3685·29	60·704
¼	176·715	2485·05	49·848	¾	215·985	3712·24	60·926
½	177·500	2507·19	50·070	**69**	**216·770**	**3739·28**	**61·147**
¾	178·285	2529·42	50·291	¼	217·555	3766·43	61·369
57	**179·071**	**2551·76**	**50·513**	½	218·341	3793·67	61·591
¼	179·856	2574·19	50·735	¾	219·126	3821·02	61·812
½	180·642	2596·72	50·956	**70**	**219·912**	**3848·46**	**62·034**
¾	181·427	2619·35	51·178	¼	220·697	3875·99	62·255
58	**182·212**	**2642·08**	**51·399**	½	221·482	3903·63	62·477
¼	182·998	2664·91	51·621	¾	222·268	3931·36	62·698
½	183·783	2687·83	51·842	**71**	**223·053**	**3959·20**	**62·920**
¾	184·569	2710·85	52·064	¼	223·839	3987·13	63·141
59	**185·354**	**2733·97**	**52·285**	½	224·624	4015·16	63·363
¼	186·139	2757·19	52·507	¾	225·409	4043·28	63·585
½	186·925	2780·51	52·729	**72**	**226·195**	**4071·51**	**63·806**
¾	187·710	2803·92	52·950	¼	226·980	4099·83	64·028
60	**188·496**	**2827·44**	**53·172**	½	227·766	4128·25	64·249
¼	189·281	2851·05	53·393	¾	228·551	4156·77	64·471
½	190·066	2874·76	53·615	**73**	**229·336**	**4185·39**	**64·692**
¾	190·852	2898·56	53·836	¼	230·122	4214·11	64·914
61	**191·637**	**2922·47**	**54·048**	½	230·907	4242·92	65·135
¼	192·423	2946·47	54·279	¾	231·693	4271·83	65·357
½	193·208	2970·57	54·501	**74**	**232·478**	**4300·85**	**65·578**
¾	193·993	2994·77	54·723	¼	233·263	4329·95	65·800
62	**194·779**	**3019·07**	**54·944**	½	234·049	4359·16	66·022
¼	195·564	3043·47	55·166	¾	234·834	4388·47	66·243
½	196·350	3067·96	55·387	**75**	**235·620**	**4417·87**	**66·465**

TABLE OF CIRCUMFERENCES AND AREAS OF CIRCLES—*continued.*

Diam. in Inches.	Circum.	Area.	Side of equal Square.	Diam. in Inches.	Circum.	Area.	Side of equal Square.
¼	236·405	4447·37	66·686	¾	275·675	6047·62	77·764
½	237·190	4476·97	66·908	**88**	**276·460**	**6082·13**	**77·985**
¾	237·976	4506·67	67·129	¼	277·246	6116·74	78·207
76	**238·761**	**4536·47**	**67·351**	½	278·031	6151·44	78·428
¼	239·547	4566·36	67·572	¾	278·817	6186·25	78·650
½	240·332	4596·35	67·794	**89**	**279·602**	**6221·15**	**78·871**
¾	241·117	4626·44	68·016	¼	280·387	6256·15	79·093
77	**241·903**	**4656·63**	**68·237**	½	281·173	6291·25	79·315
¼	242·688	4686·92	68·459	¾	281·958	6326·44	79·536
½	243·474	4717·30	68·680	**90**	**282·744**	**6361·74**	**79·758**
¾	244·259	4747·79	68·902	¼	283·529	6397·13	79·979
78	**245·044**	**4778·37**	**69·123**	½	284·314	6432·62	80·201
¼	245·830	4809·05	69·345	¾	285·100	6468·21	80·422
½	246·615	4839·83	69·566	**91**	**285·885**	**6503·89**	**80·644**
¾	247·401	4870·70	69·788	¼	286·671	6539·68	80·865
79	**248·186**	**4901·68**	**70·009**	½	287·456	6573·56	81·087
¼	248·971	4932·75	70·231	¾	288·241	6611·54	81·308
½	249·757	4963·92	70·453	**92**	**289·027**	**6647·62**	**81·530**
¾	250·542	4995·19	70·674	¼	289·812	6683·80	81·751
80	**251·328**	**5026·56**	**70·896**	½	290·598	6720·07	81·973
¼	252·113	5058·62	71·117	¾	291·383	6756·45	82·195
½	252·898	5089·58	71·339	**93**	**292·168**	**6792·92**	**82·416**
¾	253·684	5121·24	71·560	¼	292·954	6829·49	82·638
81	**254·469**	**5153·00**	**71·782**	½	293·739	6866·16	82·859
¼	255·255	5184·86	72·003	¾	294·525	6902·92	83·081
½	256·040	5216·82	72·225	**94**	**295·310**	**6939·79**	**83·302**
¾	256·825	5248·87	72·446	¼	296·095	6976·75	83·524
82	**257·611**	**5281·02**	**72·668**	½	296·881	7013·81	83·746
¼	258·396	5313·27	72·880	¾	297·666	7050·97	83·967
½	259·182	5345·62	73·111	**95**	**298·452**	**7088·23**	**84·189**
¾	259·967	5378·07	73·333	¼	299·237	7125·58	84·410
83	**260·752**	**5410·62**	**73·554**	½	300·022	7163·04	84·632
¼	261·538	5443·26	73·761	¾	300·808	7200·59	84·853
½	262·323	5476·00	73·997	**96**	**301·593**	**7238·24**	**85·075**
¾	263·109	5508·84	74·219	¼	302·379	7275·99	85·296
84	**263·894**	**5541·78**	**74·440**	½	303·164	7313·84	85·518
¼	264·679	5574·81	74·662	¾	303·949	7351·78	85·739
½	265·465	5607·95	74·884	**97**	**304·735**	**7389·82**	**85·961**
¾	266·250	5641·18	75·105	¼	305·520	7427·96	86·183
85	**267·036**	**5674·51**	**75·327**	½	306·306	7466·20	86·404
¼	267·821	5707·94	75·548	¾	307·091	7504·54	86·626
½	268·606	5741·47	75·770	**98**	**307·876**	**7542·98**	**86·847**
¾	269·392	5775·09	75·991	¼	308·662	7581·51	87·069
86	**270·177**	**5808·81**	**76·213**	½	309·447	7620·14	87·290
¼	270·963	5842·63	76·434	¾	310·233	7658·87	87·512
½	271·748	5876·55	76·656	**99**	**311·018**	**7697·70**	**87·733**
¾	272·533	5910·57	76·877	¼	311·803	7736·62	87·955
87	**273·319**	**5944·69**	**77·099**	½	312·589	7775·65	88·176
¼	274·104	5978·90	77·321	¾	313·374	7814·77	88·398
½	274·890	6013·21	77·542	**100**	**314·160**	**7854·00**	**88·620**

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS.

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1	1	1	1·00000	1·00000	1·0000000
2	4	8	1·41421	1·25992	·5000000
3	9	27	1·73205	1·44225	·3333333
4	16	64	2·00000	1·58740	·2500000
5	25	125	2·23607	1·70997	·2000000
6	36	216	2·44949	1·81712	·1666667
7	49	343	2·64575	1·91293	·1428571
8	64	512	2·82843	2·00000	·1250000
9	81	729	3·00000	2·08008	·1111111
10	**100**	**1000**	**3·16228**	**2·15443**	**·1000000**
11	121	1331	3·31662	2·22398	·0909090
12	144	1728	3·46410	2·28942	·0833333
13	169	2197	3·60555	2·35133	·0769231
14	196	2744	3·74166	2·41014	·0714286
15	225	3375	3·87298	2·46621	·0666667
16	256	4096	4·00000	2·51984	·0625000
17	289	4913	4·12311	2·57128	·0588235
18	324	5832	4·24264	2·62074	·0555556
19	361	6859	4·35890	2·66840	·0526316
20	**400**	**8000**	**4·47213**	**2·71442**	**·0500000**
21	441	9261	4·58257	2·75892	·0476190
22	484	10648	4·69042	2·80203	·0454545
23	529	12167	4·79583	2·84387	·0434783
24	576	13824	4·89898	2·88450	·0416667
25	625	15625	5·00000	2·92402	·0400000
26	676	17576	5·09902	2·96250	·0384615
27	729	19683	5·19615	3·00000	·0370370
28	784	21952	5·29150	3·03659	·0357143
29	841	24389	5·38516	3·07232	·0344828
30	**900**	**27000**	**5·47723**	**3·10723**	**·0333333**
31	961	29791	5·56776	3·14138	·0322581
32	1024	32768	5·65685	3·17480	·0312500
33	1089	35937	5·74456	3·20753	·0303030
34	1156	39304	5·83095	3·23961	·0294118
35	1225	42875	5·91608	3·27107	·0285714
36	1296	46656	6·00000	3·30193	·0277778
37	1369	50653	6·08276	3·33222	·0270270
38	1444	54872	6·16441	3·36197	·0263158
39	1521	59319	6·24500	3·39121	·0256410
40	**1600**	**64000**	**6·32456**	**3·41995**	**·0250000**
41	1681	68921	6·40312	3·44822	·0243902
42	1764	74088	6·48074	3·47603	·0238095
43	1849	79507	6 55744	8·50340	·0232558
44	1936	85184	6·63325	3·53035	·0227273
45	2025	91125	6·70820	3·55689	·0222222
46	2116	97336	6·78233	3·58305	·0217391
47	2209	103823	6·85565	3·60882	·0212766
48	2304	110592	6·92820	3·63424	·0208333
49	2401	117649	7·00000	2·65930	·0204082

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
50	**2500**	**125000**	**7·07107**	**3·68403**	**·0200000**
51	2601	132651	7·14143	3·70842	·0196078
52	2704	140608	7·21110	3·73251	·0192308
53	2809	148877	7·28011	3·75628	·0188679
54	2916	157464	7·34847	3·77976	·0185185
55	3025	166375	7·41620	3·80295	·0181818
56	3136	175616	7·48331	3·82586	·0178571
57	3249	185193	7·54983	3·84850	·0175439
58	3364	195112	7·61577	3·87088	·0172414
59	3481	205379	7·68115	3·89300	·0169491
60	**3600**	**216000**	**7·74597**	**3·91487**	**·0166667**
61	3721	226981	7·81024	3·93054	·0163934
62	3844	238328	7·87401	3·95789	·0161290
63	3969	250047	7·93725	3·97906	·0158730
64	4096	262144	8·00000	4·00000	·0156250
65	4225	274625	8·06226	4·02072	·0153846
66	4356	287496	8·12404	4·04124	·0151515
67	4489	300763	8·18535	4·06155	·0149254
68	4624	314432	8·24621	4·08165	·0147059
69	4768	328509	8·30662	4·10157	·0144928
70	**4900**	**343000**	**8·36660**	**4·12128**	**·0142857**
71	5041	357911	8·42615	4·14082	·0140845
72	5184	373248	8·48528	4·16017	·0138889
73	5329	389017	8·54400	4·17934	·0136986
74	5476	405224	8·60232	4·19832	·0135135
75	5625	421875	8·66025	4·21716	·0133333
76	5776	438976	8·71780	4·23582	·0131579
77	5929	456533	8·77496	4·25432	·0129870
78	6084	474552	8·83176	4·27266	·0128205
79	6241	493039	8·88819	4·29084	·0126582
80	**6400**	**512000**	**8·94427**	**4·30887**	**·0125000**
81	6561	531441	9·00000	4·32675	·0123457
82	6724	551368	9·05538	4·34448	·0121951
83	6889	571787	9·11043	4·36207	·0120482
84	7056	592704	9·16515	4·37952	·0119048
85	7225	614125	9·21954	4·39683	·0117647
86	7396	636056	9·27362	4·41400	·0116279
87	7569	658503	9·32738	4·43104	·0114942
88	7744	681472	9·38083	4·44707	·0113636
89	7921	704969	9·43398	4·46474	·0112359
90	**8100**	**729000**	**9·48683**	**4·48140**	**·0111111**
91	8281	753571	9·53939	4·49794	·0109890
92	8464	778688	9·59166	4·51436	·0108696
93	8649	804357	9·64365	4·53065	·0107527
94	8836	830584	9·69536	4·54683	·0106383
95	9025	857374	9·74679	4·56290	·0105263
96	9216	884736	9·79796	4·57886	·0104167
97	9409	912673	9·84885	4·59470	·0103093
98	9604	941192	9·69949	4·61044	·0102041
99	9801	970299	9·94987	4·62606	·0101010

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
100	**10000**	**1000000**	**10·00000**	**4·64159**	**·0100000**
101	10201	1030301	10·04988	4·65701	·0099010
102	10404	1061208	10·09995	4·67233	·0098039
103	10609	1092727	10·14889	4·68755	·0097087
104	10816	1124864	10·19804	4·70267	·0096154
105	11025	1157625	10·24695	4·71769	·0095238
106	11236	1191016	10·29563	4·73262	·0094340
107	11449	1225043	10·34408	4·74746	·0093458
108	11664	1259712	10·39230	4·76220	·0092592
109	11881	1295029	10·44031	4·77686	·0091743
110	**12100**	**1331000**	**10·48809**	**4·79142**	**·0090909**
111	12321	1367631	10·53565	4·80590	·0090090
112	12544	1404928	10·58300	4·82028	·0089286
113	12769	1442897	10·63014	4·83459	·0088495
114	12996	1481544	10·67708	4·84881	·0087719
115	13225	1520875	10·72380	4·86294	·0086956
116	13456	1560896	10·77033	4·87700	·0086207
117	13689	1601613	10·81665	4·89097	·0085470
118	13924	1643032	10·86278	4·90487	·0084746
119	14161	1685159	10·90871	4·91868	·0084034
120	**14400**	**1728000**	**10·95445**	**4·93242**	**·0083333**
121	14641	1771561	11·00000	4·94609	·0082645
122	14884	1815848	11·04536	4·95967	·0081967
123	15129	1860867	11·09054	4·97319	·0081301
124	15376	1906624	11·13553	4·98663	·0080645
125	15625	1953125	11·18034	5·00000	·0080000
126	15876	2000376	11·22497	5·01330	·0079365
127	16129	2048383	11·26943	5·02652	·0078740
128	16384	2097152	11·31371	5·03968	·0078125
129	16641	2146689	11·35782	5·05277	·0077519
130	**16900**	**2197000**	**11·40175**	**5·06580**	**·0076923**
131	17161	2248091	11·44552	5·07875	·0076336
132	17424	2299968	11·48912	5·09164	·0075757
133	17689	2352637	11·53256	5·10447	·0075188
134	17956	2406104	11·57584	5·11723	·0074627
135	18225	2460375	11·61895	5·12993	·0074074
136	18496	2515456	11·66190	5·14256	·0073529
137	18769	2571353	11·70470	5·15514	·0072993
138	19044	2628072	11·74734	5·16765	·0072464
139	19321	2685619	11·78983	5·18010	·0071942
140	**19600**	**2744000**	**11·83216**	**5·19249**	**·0071428**
141	19881	2803221	11·87434	5·20483	·0070922
142	20164	2863288	11·91637	5·21710	·0070422
143	20449	2924207	11·95826	5·22932	·0069930
144	20736	2985984	12·00000	5·24148	·0069444
145	21025	3048625	12·04159	5·25359	·0068965
146	21316	3112136	12·08305	5·26564	·0068493
147	21609	3176523	12·12435	5·27763	·0068027
148	21904	3241792	12·16552	5·28957	·0067567
149	22201	3307949	12·20655	5·30146	·0067114

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TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
150	**22500**	**3375000**	**12·24745**	**5·31329**	**·0066666**
151	22801	3442951	12·28820	5·32507	·0066225
152	23104	3511008	12·32883	5·33680	·0065789
153	23409	3581577	12·36932	5·34848	·0065359
154	23716	3652264	12·40967	5·36011	·0064935
155	24025	3723875	12·44990	5·37168	·0064516
156	24336	3796416	12·49000	5·38321	·0064102
157	24649	3869893	12·52996	5·39469	·0063694
158	24964	3944312	12·56980	5·40612	·0063291
159	25281	4019679	12·60952	5·41750	·0062893
160	**25600**	**4096000**	**12·64911**	**5·42883**	**·0062500**
161	25921	4173281	12·68858	5·44012	·0062112
162	26244	4251528	12 72792	5·45136	·0061728
163	26569	4330747	12·76714	5·46255	·0061350
164	26896	4410944	12·80625	5·47370	0060976
165	27225	4492125	12·84523	5·48481	·0060606
166	27556	4574296	12·88410	5·49586	·0060241
167	27889	4657463	12·92285	5·50688	0059880
168	28224	4741632	12·96148	5·51785	·0059524
169	28561	4826809	13·00000	5·52877	·0059172
170	**28900**	**4913000**	**13·03840**	**5·53966**	**·0058823**
171	29241	5000211	13·07670	5 55050	0058479
172	29584	5088448	13·11488	5·56130	·0058139
173	29929	5177717	13·15295	5·57205	·0057803
174	30276	5268024	13·19091	5·58277	·0057471
175	30625	5359375	13·22876	5·59344	·0057143
176	30976	5451776	13·26650	5·60408	·0056818
177	31329	5545233	13·30413	5·61467	·0056497
178	31684	5639752	13·34166	5·62522	·0056180
179	32041	5735339	13·37909	5·63574	·0055866
180	**32400**	**5832000**	**13·41641**	**5·64622**	**·0055556**
181	32761	5929741	13·45362	5·65665	·0055249
182	33124	6028568	13·49074	5·66705	·0054945
183	33489	6128487	13·52775	5·67741	·0054645
184	33856	6229504	13·56466	5·68773	·0054348
185	34225	6331625	13·60147	5·69802	·0054054
186	34596	6434856	13·63818	5·70827	·0053763
187	34969	6539203	13·67479	5·71848	·0053476
188	35344	6644672	13·71131	5·72865	·0053191
189	35721	6751269	13·74773	5·73879	·0052910
190	**36100**	**6859000**	**13·78405**	**5·74890**	**·0052631**
191	36481	6967871	13·82027	5·75896	·0052356
192	36864	7077888	13·85641	5·76900	·0052083
193	37249	7189517	13·89244	5·77900	0051813
194	37636	7301384	13·92839	5·78896	·0051546
195	38025	7414875	13·96424	5·79889	·0051282
196	38416	7529536	14·00000	5·80878	·0051020
197	38809	7645373	14·03567	5·81865	·0050761
198	39204	7762392	14·07125	5·82849	·0050505
199	39601	7880599	14·10674	5·83827	·0050251

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
200	**40000**	**8000000**	**14·14213**	**5·84803**	**·0050000**
201	40401	8120601	14·17745	5·85777	·0049751
202	40804	8242408	14·21267	5·86747	·0049505
203	41209	8365427	14·24781	5·87713	·0049261
204	41616	8489664	14·28286	5·88676	·0049020
205	42025	8615125	14·31782	5·89637	·0048780
206	42436	8741816	14·35270	5·90594	·0048544
207	42849	8869743	14·38749	5·91548	·0048309
208	43264	8998912	14·42220	5·92499	·0048077
209	43681	9129329	14·45683	5·93447	·0047847
210	**44100**	**9261000**	**14·49138**	**5·94392**	**·0047619**
211	44521	9393931	14·52584	5·95334	·0047393
212	44944	9528128	14·56022	5·96273	·0047170
213	45369	9663597	14·59452	5·97209	·0046948
214	45796	9800344	14·62874	5·98142	·0046729
215	46225	9938375	14·66288	5·99073	·0046512
216	46656	10077696	14·69694	6·00000	·0046296
217	47089	10218313	14·73092	6·00924	·0046083
218	47524	10360232	14·76482	6·01846	·0045871
219	47961	10503459	14·79865	6·02765	·0045662
220	**48400**	**10648000**	**14·83240**	**6·03681**	**·0045454**
221	48841	10793861	14·86607	6·04594	·0045249
222	49284	10941048	14·89966	6·05505	·0045045
223	49729	11089567	14·93318	6·06413	·0044843
224	50176	11239424	14·96663	6·07318	·0044643
225	50625	11390625	15·00000	6·08240	·0044444
226	51076	11543176	15·03330	6·09920	·0044248
227	51529	11697083	15·06652	6·10017	·0044053
228	51984	11852352	15·09967	6·10911	·0043860
229	52441	12008989	15·13275	6·11803	·0043668
230	**52900**	**12167000**	**15·16575**	**6·12692**	**·0043478**
231	53361	12326391	15·19868	6·13579	·0043290
232	53824	12487168	15·23155	6·14463	·0043103
233	54289	12649337	15·26434	6·15345	·0042918
234	54756	12812904	15·29706	6·16224	·0042735
235	55225	12977875	15·32971	6·17100	·0042553
236	55696	13144256	15·36229	6·17975	·0042373
237	56169	13312053	15·39480	6·18846	·0042194
238	56644	13481272	15·42725	6·19715	·0042017
239	57121	13651919	15·45962	6·20582	·0041841
240	**57600**	**13824000**	**15·49193**	**6·21446**	**·0041667**
241	58081	13997521	15·52417	6·22308	·0041494
242	58564	14172488	15·55635	6·23168	·0041322
243	59049	14348907	15·58846	6·24025	·0041152
244	59536	14526784	15·62050	6·24880	·0040984
245	60025	14706125	15·65247	6·25732	·0040816
246	60516	14886936	15·68439	6·26583	·0040650
247	61009	15069223	15·71623	6·27430	·0040486
248	61504	15252992	15·74801	6·28276	·0040322
249	62001	15438249	15·77973	6·29119	·0040161

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
250	**62500**	**15625000**	**15·81139**	**6·29960**	**·0040000**
251	63001	15813251	15·84298	6 30799	·0039841
252	63504	16003008	15·87451	6·31636	·0039682
253	64009	16194277	15·90597	6·32470	·0039526
254	64516	16387064	15·93738	6·33302	·0039370
255	65025	16581375	15·96872	6·34132	·0039216
256	65536	16777216	16·00000	6·34960	·0039062
257	66049	16974593	16·03122	6·35786	·0038910
258	66564	17173512	16·06238	6·36610	·0038760
259	67081	17373979	16·09348	6·37431	·0038610
260	**67600**	**17576000**	**16·12451**	**6·38250**	**·0038461**
261	68121	17779581	16·15549	6·39068	·0038314
262	68644	17984728	16·18641	6·39883	·0038168
263	69169	18191447	16·21727	6·40696	·0038023
264	69696	18399744	16·24808	6·41507	·0037879
265	70225	18609625	16·27882	6·42316	·0037736
266	70756	18821096	16·30951	6·43123	·0037594
267	71289	19034163	16·34013	6·43928	·0037453
268	71824	19248832	16·37070	6·44730	·0037313
269	72361	19465109	16·40122	6·45531	·0037175
270	**72900**	**19683000**	**16·43168**	**6·46330**	**·0037037**
271	73441	19902511	16·46208	6·47127	·0036900
272	73984	20123648	16·49242	6·47922	·0036765
273	74529	20346417	16·52271	6·48715	·0036630
274	75076	20570824	16·55294	6·49506	·0036496
275	75625	20796875	16·58312	6·50296	·0036364
276	76176	21024576	16·61325	6 51083	·0036232
277	76729	21253933	16·64332	6·51868	·0036101
278	77284	21484952	16·67833	6·52652	·0035971
279	77841	217[illegible]7639	16·70329	6·53433	·0035842
280	**78400**	**21952000**	**16·73320**	**6·54213**	**·0035714**
281	78961	22188041	16·76305	6·54991	·0035587
282	79524	22425768	16·79285	6·55767	·0035461
283	80089	22665187	16·82260	6·56541	·0035336
284	80656	22906304	16·85230	6·57314	·0035221
285	81225	23149125	16·88194	6·58084	·0035088
286	81796	23393656	16·91153	6·58853	·0034965
287	82369	23639903	16.94107	6·59620	·0034843
288	82944	23887872	16·97056	6·60385	·0034722
289	83521	24137569	17·00000	6·61149	·0034602
290	**84100**	**24389000**	**17·02939**	**6·61911**	**·0034483**
291	84681	24642171	17·05872	6·62670	·0034364
292	85264	24897088	17·08801	6·63429	·0034246
293	85849	25153757	17·11724	6·64185	·0034130
294	86436	25412184	17·14643	6·64940	·0034014
295	87025	25672375	17·17556	6·65693	·0033898
296	87616	25934836	17·20465	6·66444	·0033784
297	88209	26198073	17·23369	6 67194	·0033670
298	88804	26463592	17·26268	6·67942	·0033557
299	89401	26730899	17·29162	6·68688	·0033445

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
300	**90000**	**27000000**	**17·32051**	**6·69433**	**·0033333**
301	90601	27270901	17·34935	6·70176	·0033222
302	91204	27543608	17·37815	6·70917	·0033112
303	91809	27818127	17·40689	6·71657	·0033013
304	92416	28094464	17·43559	6·72395	·0032895
305	93025	28372625	17·46425	6·73131	·0032787
306	93636	28652616	17·49285	6·73866	·0032680
307	94249	28934443	17·52141	6·74600	·0032573
308	94864	29218112	17·54993	6·75331	·0032467
309	95481	29503609	17·57839	6·76061	·0032362
310	**96100**	**29791000**	**17·60682**	**6·76790**	**·0032258**
311	96721	30080231	17·63519	6·77517	·0032154
312	97344	30371328	17·66352	6·78242	·0032051
313	97969	30664297	17·69181	6·78966	·0031949
314	98596	30959144	17·72004	6·79688	·0031847
315	99225	31255875	17·74824	6·80409	·0031746
316	99856	31554496	17·77639	6·81128	·0031645
317	100489	31855013	17·80449	6·81846	·0031546
318	101124	32157432	17·83255	6·82562	·0031446
319	101761	32461759	17·86057	6·83277	·0031348
320	**102400**	**32768000**	**17·88854**	**6·83990**	**·0031250**
321	103041	33076161	17·91647	6·84702	·0031153
322	103684	33386248	17·94436	6·85412	·0031056
323	104329	33698267	17·97220	6·86121	·0030960
324	104976	34012224	18·00000	6·86828	·0030864
325	105625	34328125	18·02776	6·87534	·0030769
326	106276	34645976	18·05547	6·88239	·0030675
327	106929	34965783	18·08314	6·88942	·0030581
328	107584	35287552	18·11077	6·89643	·0030488
329	108241	35611289	18·13836	6·90343	·0030395
330	**108900**	**35937000**	**18·16590**	**6·91042**	**·0030303**
331	109561	36264691	18·19340	6·91740	·0030211
332	110224	36594368	18·22087	6·92435	·0030120
333	110889	36926037	18·24829	6·93131	·0030030
334	111556	37259704	18·27567	6·93823	·0029940
335	112225	37595375	18·30300	6·94515	·0029851
336	112896	37933056	18·33030	6·95205	·0029762
337	113569	38272753	18·35756	6·95894	·0029673
338	114244	38614472	18·38478	6·96582	·0029586
339	114921	38958219	18·41195	6·97268	·0029498
340	**115600**	**39304000**	**18·43909**	**6·97953**	**·0029412**
341	116281	39651821	18·46618	6·98637	·0029325
342	116964	40001688	18·49324	6·99319	·0029240
343	117649	40353607	18·52026	7·00000	·0029154
344	118336	40707584	18·54724	7·00680	·0029070
345	119025	41063625	18·57417	7·01358	·0028985
346	119716	41421736	18·60107	7·02035	·0028902
347	120409	41781923	18·62794	7·02710	·0028818
348	121104	42144192	18·65476	7·03385	·0028736
349	121801	42508549	18·68154	7·04059	·0028653

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
350	**122500**	**42875000**	**18·70829**	**7·04730**	**·0028571**
351	123201	43243551	18·73499	7·05400	·0028490
352	123904	43614208	18·76166	7·06070	·0028409
353	124609	43986977	18·78829	7·06738	·0028329
354	125316	44361864	18·81489	7·07404	·0028248
355	126025	44738875	18·84144	7·08070	·0028170
356	126736	45118016	18·86796	7·08734	·0028090
357	127449	45499293	18·89444	7·09397	·0028011
358	128164	45882712	18·92089	7·10059	·0027933
359	128881	46268279	18·94729	7·10719	·0027855
360	**129600**	**46656000**	**18·97367**	**7·11379**	**·0027778**
361	130321	47045831	19·00000	7·12037	·0027701
362	131044	47437928	19·02630	7·12694	·0027624
363	131769	47832147	19·05256	7·13349	·0027548
364	132496	48228544	19·07878	7·14004	·0027472
365	133225	48627125	19·10497	7·14657	·0027397
366	133956	49027896	19·13113	7·15309	·0027322
367	134689	49430863	19·15724	7·15960	·0027248
368	135424	49836032	19·18333	7·16609	·0027174
369	136161	50243409	19·20937	7·17258	·0027100
370	**136900**	**50653000**	**19·23538**	**7·17905**	**·0027027**
371	137641	51064811	19·26136	7·18552	·0026954
372	138384	51478848	19·28730	7·19197	·0026882
373	139129	51895117	19·31321	7·19840	·0026810
374	139876	52313624	19·33908	7·20483	·0026738
375	140625	52734375	19·36492	7·21125	·0026667
376	141376	53157376	19·39072	7·21765	·0026596
377	142129	53582633	19·41649	7·22404	·0026525
378	142884	54010152	19·44222	7·23043	·0026455
379	143641	54439939	19·46792	7·23680	·0026385
380	**144400**	**54872000**	**19·49359**	**7·24316**	**·0026316**
381	145161	55306341	19·51922	7·24950	·0026247
382	145924	55742968	19·54482	7·25584	·0026178
383	146689	56181887	19·57038	7·26217	·0026110
384	147456	56623104	19·59591	7·26848	·0026042
385	148225	57066625	19·62142	7·27479	·0025974
386	148996	57512456	19·64688	7·28108	·0025907
387	149769	57960603	19·67231	7·28736	·0025840
388	150544	58411072	19·69771	7·29363	·0025773
389	151321	58863869	19·72308	7·29989	·0025707
390	**152100**	**59319000**	**19·74842**	**7·30614**	**·0025641**
391	152881	59776471	19·77372	7·31238	·0025575
392	153664	60236288	19·79899	7·31861	·0025510
393	154449	60698457	19·82423	7·32483	·0025445
394	155236	61162984	19·84943	7·33104	·0025381
395	156025	61629875	19·87461	7·33723	·0025316
396	156816	62099136	19·89975	7·34342	·0025252
397	157609	62570773	19·92486	7·34960	·0025189
398	158404	63044792	19·94994	7·35576	·0025126
399	159201	63521199	19·97498	7·36192	·0025063

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
400	**160000**	**64000000**	**20·00000**	**7·36806**	**·0025000**
401	160801	64481201	20·02498	7·37420	·0024938
402	161604	64964808	20·04994	7·38032	·0024876
403	162409	65450827	20·07486	7·38644	·0024814
404	163216	65939264	20·09975	7·39254	·0024752
405	164025	66430125	20·12461	7·39864	·0024691
406	164836	66923416	20·14944	7·40472	·0024630
407	165649	67419143	20·17424	7·41079	·0024570
408	166464	67917312	20·19901	7·41686	·0024510
409	167281	68417929	20·22375	7·42291	·0024450
410	**168100**	**68921000**	**20·24846**	**7·42896**	**·0024390**
411	168921	69426531	20·27313	7·43499	·0024331
412	169744	69934528	20·29778	7·44102	·0024272
413	170569	70444997	20·32240	7·44703	·0024213
414	171396	70957944	20·34699	7·45304	·0024154
415	172225	71473375	20·37155	7·45903	·0024096
416	173056	71991296	20·39608	7·46502	·0024068
417	173889	72511713	20·42058	7·47100	·0023981
418	174724	73034632	20·44505	7·47697	·0023923
419	175561	73560059	20·46949	7·48292	·0023866
420	**176400**	**74088000**	**20·49390**	**7·48887**	**.0023809**
421	177241	74618461	20·51828	7·49481	·0023753
422	178084	75151448	20·54264	7·50074	·0023697
423	178929	75686967	20·56696	7·50666	·0023641
424	179776	76225024	20·59126	7·51257	·0023585
425	180625	76765625	20·61553	7·51847	·0023529
426	181476	77308776	20·63977	7·52436	·0023474
427	182329	77854483	20·66398	7·53025	·0023419
428	183184	78402752	20·68816	7·53612	·0023364
429	184041	78953539	20·71231	7·54199	·0023310
430	**184900**	**79507000**	**20·73644**	**7·54784**	**·0023256**
431	185761	80062991	20·76054	7·55369	·0023202
432	186624	80621568	20·78461	7·55953	·0023148
433	187489	81182737	20·80865	7·56535	·0023095
434	188356	81746504	20·83267	7·57117	·0023041
435	189225	82312875	20·85665	7·57698	·0022988
436	190096	82881856	20·88061	7·58279	·0022936
437	190969	83453453	20·90454	7·58858	·0022883
438	191844	84027672	20·92845	7·59436	·0022831
439	192721	84604519	20·95233	7·60014	·0022779
440	**193600**	**85184000**	**20·97618**	**7·60590**	**·0022727**
441	194481	85766121	21·00000	7·61166	·0022676
442	195364	86350888	21·02380	7·61741	·0022624
443	196249	86938307	21·04757	7·62315	·0022573
444	197136	87528384	21·07131	7·62888	·0022522
445	198025	88121125	21·09502	7·63461	·0022472
446	198916	88716536	21·11871	7·64032	·0022421
447	199809	89314623	21·14237	7·64603	·0022371
448	200704	89915392	21·16601	7·65172	·0022321
449	201601	90518849	21·18962	7·65741	·0022272

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
450	**202500**	**91125000**	**21·21320**	**7·66309**	**·0022222**
451	203401	91733851	21·23676	7·66877	·0022173
452	204304	92345408	21·26029	7·67443	·0022124
453	205209	92959677	21·28380	7·68008	·0022075
454	206116	93576664	21·30727	7·68573	·0022026
455	207025	94196375	21·33073	7·69137	·0021978
456	207936	94818816	21·35416	7·69700	·0021930
457	208849	95443993	21·37756	7·70262	·0021882
458	209764	96071912	21·40093	7·70824	·0021834
459	210681	96702579	21·42428	7·71384	·0021786
460	**211600**	**97336000**	**21·44761**	**7·71944**	**·0021739**
461	212521	97972181	21·47091	7·72503	·0021692
462	213444	98611128	21·49418	7·73061	·0021645
463	214369	99252847	21·51743	7·73619	·0021598
464	215296	99897344	21·54066	7·74175	·0021552
465	216225	100544625	21·56386	7·74731	·0021505
466	217156	101194696	21·58703	7·75286	·0021459
467	218089	101847563	21·61018	7·75840	·0021413
468	219024	102503232	21·63331	7·76394	·0021367
469	219961	103161709	21·65641	7·76946	·0021322
470	**220900**	**103823000**	**21·67948**	**7·77498**	**·0021277**
471	221841	104487111	21·70253	7·78049	·0021231
472	222784	105154048	21·72556	7·78599	·0021186
473	223729	105823817	21·74856	7·79149	·0021142
474	224676	106496424	21·77154	7·79697	·0021097
475	225625	107171875	21·79449	7·80245	·0021053
476	226576	107850176	21·81742	7·80792	·0021008
477	227529	108531333	21·84033	7·81339	·0020965
478	228484	109215352	21·86321	7·81884	·0020920
479	229441	109902239	21·88607	7·82429	·0020877
480	**230400**	**110592000**	**21·90890**	**7·82973**	**·0020833**
481	231361	111284641	21·93171	7·83517	·0020790
482	232324	111980168	21·95450	7·84059	·0020747
483	233289	112678587	21·97726	7·84601	·0020704
484	234256	113379904	22·00000	7·85142	·0020661
485	235225	114084125	22·02271	7·85683	·0020619
486	236196	114791256	22·04541	7·86222	·0020576
487	237169	115501303	22·06808	7·86761	·0020534
488	238144	116214272	22·09072	7·87299	·0020492
489	239121	116930169	22·11334	7·87837	·0020450
490	**240100**	**117649000**	**22·13594**	**7·88373**	**·0020408**
491	241081	118370771	22·15852	7·88909	·0020367
492	242064	119095488	22·18107	7·89445	·0020325
493	243049	119823157	22·20360	7·89979	·0020284
494	244036	120553784	22·22611	7·90513	·0020243
495	245025	121287375	22·24859	7·91046	·0020202
496	246016	122023936	22·27106	7·91578	·0020161
497	247009	122763473	22·29350	7·92110	·0020121
498	248004	123505992	22·31591	7·92641	·0020080
499	249001	124251499	22·33831	7·93171	·0020040

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
500	**250000**	**125000000**	**22·36068**	**7·93700**	**·0020000**
501	251001	125751501	22·38303	7·94229	·0019960
502	252004	126506008	22·40536	7·94757	·0019920
503	253009	127263527	22·42766	7·95285	·0019881
504	254016	128024064	22·44994	7·95811	·0019841
505	255025	128787625	22·47220	7·96337	·0019802
506	256036	129554216	22·49444	7·96863	·0019763
507	257049	130323843	22·51666	7·97387	·0019724
508	258064	131096512	22·53885	7·97911	·0019685
509	259081	131872229	22·56103	7·98434	·0019646
510	**260100**	**132651000**	**22·58318**	**7·98957**	**·0019608**
511	261121	133432831	22·60531	7·99479	·0019569
512	262144	134217728	22·62742	8·00000	·0019531
513	263169	135005697	22·64950	8·00520	·0019493
514	264196	135796744	22·67157	8·01040	·0019455
515	265225	136590875	22·69361	8·01559	·0019417
516	266256	137388096	22·71563	8·02078	·0019380
517	267289	138188413	22·73763	8·02596	·0019342
518	268324	138991832	22·75961	8·03113	·0019305
519	269361	139798359	22·78157	8·03629	·0019268
520	**270400**	**140608000**	**22·80351**	**8·04145**	**·0019231**
521	271441	141420761	22·82542	8·04660	·0019194
522	272484	142236648	22·84732	8·05175	·0019157
523	273529	143055667	22·86919	8·05689	·0019120
524	274576	143877824	22·89105	8·06202	·0019084
525	275625	144703125	22·91288	8·06714	·0019048
526	276676	145531576	22·93469	8·07226	·0019011
527	277729	146363183	22·95648	8·07737	·0018975
528	278784	147197952	22·97825	8·08248	·0018939
529	279841	148035889	23·00000	8·08758	·0018903
530	**280900**	**148877001**	**23·02173**	**8·09267**	**·0018868**
531	281961	149721291	23·04344	8·09776	·0018832
532	283024	150568768	23·06512	8·10284	·0018797
533	284089	151419437	23·08679	8·10791	·0018761
534	285156	152273304	23·10844	8·11298	·0018726
535	286225	153130375	23·13007	8·11804	·0018691
536	287296	153990656	23·15167	8·12310	·0018657
537	288369	154854153	23·17326	8·12814	·0018622
538	289444	155720872	23·19483	8·13319	·0018587
539	290521	156590819	23·21637	8·13822	·0018553
540	**291600**	**157464000**	**23·23790**	**8·14325**	**·0018518**
541	292681	158340421	23·25941	8·14828	·0018484
542	293764	159220088	23·28089	8·15329	·0018450
543	294849	160103007	23·30236	8·15830	·0018416
544	295936	160989184	23·32381	8·16331	·0018382
545	297025	161878625	23·34523	8·16831	·0018349
546	298116	162771336	23·36664	8·17330	·0018315
547	299209	163667323	23·38803	8·17829	0018281
548	300304	164566592	23·40940	8·18327	·0018248
549	301401	165469149	23·43075	8·18824	·0018215

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
550	**302500**	**166375000**	**23·45208**	**8·19321**	**·0018182**
551	303601	167284151	23·47339	8·19817	·0018149
552	304704	168196608	23·49468	8·20313	·0018116
553	305809	169112377	23·51595	8·20808	·0018083
554	306916	170031464	23·53720	8·21303	·0018050
555	308025	170953875	23·55844	8·21796	·0018018
556	309136	171879616	23·57965	8·22290	·0017986
557	310249	172808693	23·60085	8·22782	·0017953
558	311364	173741112	23·62202	8·23275	·0017921
559	312481	174676879	23·64318	8·23766	·0017889
560	**313600**	**175616000**	**23·66432**	**8·24257**	**·0017857**
561	314721	176558481	23·68544	8·24747	·0017825
562	315844	177504328	23·70654	8·25237	·0017793
563	316969	178453547	23·72762	8·25726	·0017762
564	318096	179406144	23·74868	8·26215	·0017730
565	319225	180362125	23·76973	8·26703	·0017699
566	320356	181321496	23·79075	8·27190	·0017668
567	321489	182284263	23·81176	8·27677	·0017637
568	322624	183250432	23·83275	8·28162	·0017606
569	323761	184220009	23·85372	8·28649	·0017575
570	**324900**	**185193000**	**23·87467**	**8·29134**	**·0017544**
571	326041	186169411	23·89561	8·29619	·0017513
572	327184	187149248	23·91652	8·30103	·0017482
573	328329	188132517	23·93742	8·30586	·0017452
574	329476	189119224	23·95830	8·31069	·0017422
575	330625	190109375	23·97916	8·31552	·0017391
576	331776	191102976	24·00000	8·32033	·0017361
577	332927	192100033	24·02082	8·32515	·0017331
578	334084	193100552	24·04163	8·32995	·0017301
579	335241	194104539	24·06242	8·33475	·0017271
580	**336400**	**195112000**	**24·08319**	**8·33955**	**·0017241**
581	337561	196122941	24·10394	8·34434	·0017212
582	338724	197137368	24·12468	8·34912	·0017182
583	339889	198155287	24·14539	8·35390	·0017153
584	341056	199176704	24·16609	8·35868	·0017123
585	342225	200201625	24·18677	8·36345	·0017094
586	343396	201230056	24·20744	8·36821	·0017065
587	344569	202262003	24·22808	8·37297	·0017036
588	345744	203297472	24·24871	8·37772	·0017007
589	346921	204336469	24·26932	8·38246	·0016978
590	**348100**	**205379000**	**24·28991**	**8·38721**	**·0016949**
591	349281	206425071	24·31050	8·39194	·0016920
592	350464	207474688	24·33105	8·39667	·0016892
593	351649	208527857	24·35159	8·40140	·0016863
594	352836	209584584	24·37211	8·40612	·0016835
595	354025	210644875	24·39262	8·41083	·0016807
596	355216	211708736	24·41311	8·41554	·0016778
597	356409	212776173	24·43358	8·42025	·0016750
598	357604	213847192	24·45404	8·42494	·0016722
599	358801	214921799	24·47448	8·42964	·0016694

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
600	**360000**	**216000000**	**24·49490**	**8·43433**	**·0016667**
601	361201	217081801	24·51530	8·43901	·0016639
602	362404	218167208	24·53569	8·44369	·0016611
603	363609	219256227	24·55606	8 44836	·0016584
604	364816	220348864	24·57641	8·45303	·0016557
605	366025	221445125	24·59675	8·45769	·0016529
606	367236	222545016	24·61707	8·46235	·0016502
607	368449	223648543	24·63737	8·46700	·0016474
608	369664	224755712	24·65766	8·47165	·0016447
609	370881	225866529	24·67792	8·47629	·0016420
610	**372100**	**226981000**	**24·69818**	**8·48093**	**·0016393**
611	373321	228099131	24·71841	8·48556	·0016367
612	374544	229220928	24·73863	8·49018	·0016340
613	375769	230346397	24·75884	8·49481	·0016313
614	376996	231475544	24·77902	8·49942	·0016287
615	378225	232608375	24·79919	8·50403	·0016260
616	379456	233744896	24·81935	8·50864	·0016234
617	380689	234885113	24·83948	8·51324	·0016207
618	381924	236029032	24·85960	8·51784	·0016181
619	383161	237176659	24·87971	8·52243	·0016155
620	**384400**	**238328000**	**24·89980**	**8·52702**	**·0016129**
621	385641	239483061	24·91987	8·53160	·0016103
622	386884	240641848	24·93993	8·53618	·0016077
623	388129	241804367	24·95997	8 54075	·0016051
624	389376	242970624	24·97999	8·54532	0016026
625	390625	244140625	25·00000	8·54988	0016000
626	391876	245134376	25·01999	8·55444	0015974
627	393129	246491883	25·03997	8·55899	·0015949
628	394384	247673152	25·05993	8·56354	·0015923
629	395641	248858189	25·07987	8·56808	·0015898
630	**396900**	**250047000**	**25·09980**	**8·57262**	**·0015873**
631	398161	251239591	25·11971	8·57715	·0015848
632	399424	252435968	25·13961	8·58168	·0015823
633	400689	253636137	25·15949	8·58622	·0015798
634	401956	254840104	25·17936	8·59072	·0015773
635	403225	256047875	25·19921	8·59524	·0015748
636	404496	257259456	25·21904	8·59975	·0015723
637	405769	258474853	25·23886	8·60425	·0015698
638	407044	259694072	25·25866	8·60875	·0015674
639	408321	260917119	25·27845	8·61325	·0015649
640	**409600**	**262144000**	**25·29822**	**8·61774**	**·0015625**
641	410881	263374721	25·31798	8·62222	·0015601
642	412164	264609288	25·33772	8·62671	·0015576
643	413449	265847707	25·35744	8·63118	·0015552
644	414736	267089984	25·37715	8·63565	·0015528
645	416125	268336125	25·39685	8·64012	·0015504
646	417316	269585136	25·41653	8·64458	·0015480
647	418609	270840023	25·43619	8·64904	·0015456
648	419904	272097792	25·45584	8·65350	·0015432
649	421201	273359449	25·47548	8·65795	·0015408

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
650	**422500**	**274625000**	**25·49510**	**8·66239**	**·0015385**
651	423801	275894451	25·51470	8·66683	·0015361
652	425104	277167808	25·53429	8·67127	·0015337
653	426409	278445077	25·55386	8·67570	·0015314
954	427716	279726264	25·57342	8·68012	·0015290
655	429025	281011375	25·59297	8·68454	·0015267
656	430336	282300416	25·61250	8·68896	·0015244
657	431639	283593393	25·63201	8·69337	·0015221
658	432964	284890312	25·65151	8·69778	·0015197
659	434281	286191179	25·67010	8·70219	·0015174
660	**435600**	**287496000**	**25·69046**	**8·70659**	**·0015151**
661	436921	288804781	25·70992	8·71098	·0015128
662	428244	290117528	25·72936	8·71537	·0015106
663	439569	291434247	25·74879	8·71976	·0015083
664	440896	292754944	25·76820	8·72414	·0015060
665	442225	294079625	25·78759	8·72852	·0015037
666	443556	295408296	25·80697	8·73289	·0015015
667	444899	296740963	25·82634	8·73726	·0014992
668	446224	298077632	25·84570	8·74162	·0014970
669	447561	299418309	25·86503	8·74598	·0014948
670	**448900**	**300763000**	**25·88436**	**8·75034**	**·0014925**
671	450241	302111711	25·90367	8·75469	·0014903
672	451584	303464448	25·92296	8·75904	·0014881
673	452929	304821217	25·94224	8·76338	·0014859
674	454276	306182024	25·96151	8·76772	·0014837
675	455625	307546875	25·98076	8·77205	·0014815
676	456976	308915776	26·00000	8·77638	·0014793
677	458329	310288733	26·01922	8·78071	·0014771
678	459684	311665752	26·03843	8·78503	·0014749
679	461041	313046839	26·05763	8·78935	·0014727
680	**462400**	**314432000**	**26·07681**	**8·79366**	**·0014706**
681	463761	315821241	26·09598	8·79797	·0014684
682	465124	317214568	26·11513	8·80227	·0014663
683	466489	318611987	26·13427	8·80657	·0014641
684	467856	320013504	26·15339	8·81087	·0014620
685	469225	321419125	26·17250	8·81516	·0014598
686	470596	322828856	26·19160	9·81945	·0014577
687	471969	324242703	26·21068	8·82373	·0014556
688	473344	325660672	26·22975	8·82801	·0014535
689	474721	327082769	26·24881	8·83228	·0014514
690	**476100**	**328509000**	**26·26785**	**8·83655**	**·0014493**
691	477481	329939371	26·28688	8·84082	·0014472
692	478864	331373888	26·30589	8·84508	·0014451
693	480249	332812557	26·32489	8·84934	·0014430
694	481636	334255384	26·34388	8·85360	·0014409
695	483025	335702375	26·36285	8·85785	·0014383
696	484416	337153536	26·38181	8·86209	·0014368
697	485809	338608873	26·40076	8·86634	·0014347
698	487204	340068392	26·41969	8·87057	·0014327
699	488601	341532099	26·43861	8·87481	·0014306

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
700	**490000**	**343000000**	**26·45751**	**8·87904**	**0014286**
701	491401	344472101	26·47640	8·88327	·0014265
702	492804	345948408	26·49528	8·88749	·0014245
703	494209	347428927	26·51415	8·89171	·0014225
704	495616	348913664	26·53300	8·89592	·0014204
705	497025	350402625	26·55184	8·90013	·0014184
706	498436	351895816	26·57066	8·90434	·0014164
707	499849	353393243	26·58947	8·90854	·0014144
708	501264	354894912	26·60827	8·91274	·0014124
709	502681	356400829	26·62705	8·91693	·0014104
710	**504100**	**357911000**	**26·64582**	**8·92112**	**·0014084**
711	505521	359425431	26·66458	8·92531	·0014065
712	506944	360944128	26·68333	8·92949	·0014045
713	508369	362467097	26·70206	8·93367	·0014025
714	509796	363994344	26·72078	8·93784	·0014006
715	511225	365525875	26·73948	8·94201	·0013986
716	512656	367061696	26·75818	8·94618	·0013966
717	514089	368601813	26·77685	8·95034	·0013947
718	515524	370146232	26·79552	8·95450	·0013928
719	516961	371694959	26·81417	8·95866	·0013908
720	**518400**	**373248000**	**26·83281**	**8·96281**	**·0013889**
721	519841	374805361	26·85144	8·96696	·0013870
722	521284	376367048	26·87006	8·97110	·0013850
723	522729	377933067	26·88866	8·97524	·0013831
724	524176	379503424	26·90725	8·97938	·0013812
725	525625	381078125	26·92582	8·98351	·0013793
726	527076	382657176	26·94439	8·98764	·0013774
727	528529	384240583	26·96294	8·99176	·0013755
728	529984	385828352	26·98147	8·99589	·0013736
729	531441	387420489	27·00000	9·00000	·0013717
730	**532900**	**389017000**	**27·01851**	**9·00411**	**·0013699**
731	534361	390617891	27·03701	9·00822	·0013680
732	535824	392223168	27·05550	9·01233	·0013661
733	537289	393832837	27·07397	9·01643	·0013642
734	538756	395446904	27·09243	9·02053	·0013624
735	540225	397065375	27·11088	9·02462	·0013605
736	541696	398688256	27·12932	9·02871	·0013587
737	543169	400315553	27·14771	9·03280	·0013568
738	544644	401947272	27·16615	9·03688	·0013550
739	546121	403583419	27·18455	9·04096	·0013532
740	**547600**	**405224000**	**27·20291**	**9·04504**	**·0013513**
741	549801	406869021	27·22131	9·04911	·0013495
742	550564	408518488	27·23968	9·05318	·0013477
743	552049	410172407	27·25803	9·05725	·0013459
744	553536	411830784	27·27636	9·06131	·0013441
745	555025	413493625	27·29469	9·06537	·0013423
746	556516	415160936	27·31300	9·06942	·0013405
747	558009	416832723	27·33130	9·07347	·0013387
748	559504	418508992	27·34959	9·07752	·0013369
749	561001	420189749	27·36786	9·08156	·0013351

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
750	**562500**	**421875000**	**27·38613**	**9·08560**	**·0013333**
751	564001	423564751	27·40438	9·08963	·0013315
752	565504	425259008	27·42262	9·09367	·0013298
753	567009	426957777	27·44084	9·09770	·0013280
754	568516	428661064	27·45906	9·10173	·0013263
755	570025	430368875	27·47726	9·10575	·0013245
756	571536	432081216	27·49545	9·10977	·0013227
757	573049	433798093	27·51363	9·11378	·0013210
758	574564	435519512	27·53180	9·11779	·0013193
759	576081	437245479	27·54995	9·12180	·0013175
760	**577600**	**438976000**	**27·56810**	**9·12580**	**·0013158**
761	579121	440711081	27·58623	9·12981	·0013141
762	580644	442450728	27·60435	9·13380	·0013123
763	582169	444194947	27·62245	9·13780	·0013106
764	583696	445943744	27·64055	9·14179	·0013089
765	585225	447697125	27·65863	9·14577	·0013072
766	586756	449455096	27·67670	9·14976	·0013055
767	588289	451217663	27·69476	9·15374	·0013038
768	589824	452984832	27·71281	9·15771	·0013021
769	591361	454756609	27·73085	9·16169	·0013004
770	**592900**	**456533000**	**27·74887**	**9·16566**	**·0012987**
771	594441	458314011	27·76689	9·16962	·0012970
772	595984	460099648	27·78489	9·17358	·0012953
773	597529	461889917	27·80288	9·17754	·0012937
774	599076	463684824	27·82085	9·18150	·0012920
775	600625	465484375	27·83882	9·18545	·0012903
776	602176	467288576	27·85678	9·18940	0012887
777	603729	469097433	27·87472	9·19335	·0012870
778	605284	470910952	27·89265	9·19729	·0012853
779	606841	472729139	27·91057	9·20123	·0012837
780	**608400**	**474552000**	**27·92848**	**9·20516**	**·0012820**
781	609961	476379541	27·94638	9·20910	·0012804
782	611524	478211768	27·96426	9·21302	·0012788
783	613089	480048687	27·98214	9·21695	·0012771
784	614656	481890304	28·00000	9·22087	·0012755
785	616225	483736625	28·01785	9·22479	·0012739
786	617796	485587656	28·03569	9·22871	·0012723
787	619369	487443403	28·05352	9·23262	·0012706
788	620944	489303872	28·07134	9·23653	·0012690
789	622521	491169069	28·08914	9·24043	·0012674
790	**624100**	**493039000**	**28·10694**	**9·24433**	**·0012658**
791	625681	494913671	28·12472	9·24823	·0012642
792	627624	496793088	28·14249	9·25213	·0012626
793	628849	498677257	28·16025	9·25602	·0012610
794	630436	500566184	28·17800	9·25991	·0012594
795	632025	502459875	28·19574	9·26380	0012579
796	633616	504358336	28·21347	9·26768	·0012563
797	635209	506261573	28·23119	9·27156	·0012547
798	636804	508169592	28·24889	9·27543	·0012531
799	638401	510082399	28·26659	9·27931	·0012516

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots	Cube Roots.	Reciprocals.
800	**640000**	**512000000**	**28·28427**	**9·28318**	**·0012500**
801	641601	513922401	28·30194	9·28704	·0012484
802	643204	515849608	28·31960	9·29090	·0012469
803	644809	517781627	28·33725	9·29477	·0012453
804	646416	519718464	28·35489	9·29862	·0012438
805	648025	521660125	28·37252	9·30248	·0012422
806	649636	523606616	28·39014	9·30633	·0012407
807	651249	525557943	28·40774	9·31015	·0012391
808	652864	527514112	28·42534	9·31402	·0012376
809	654481	529475129	28·44292	9·31786	·0012361
810	**656100**	**531441000**	**28·46050**	**9·32170**	**·0012346**
811	657721	533411731	28·47806	9·32553	·0012330
812	659344	535387328	28·49561	9·32936	·0012315
813	660969	537367797	28·51315	9·33319	·0012300
814	662596	539353144	28·53068	9·33702	·0012285
815	664225	541343375	28·54820	9·34084	·0012270
816	665856	543338496	22·56571	9·34466	·0012255
817	667489	545338513	28·58321	9·34847	·0012240
818	669124	547343432	28·60070	9·35228	·0012225
819	670761	549353259	28·61818	9·35609	·0012210
820	**672400**	**551368000**	**28·63564**	**9·35990**	**·0012195**
821	674041	553387661	28·65310	9·36370	·0012180
822	675684	555412248	28·67054	9·36750	·0012165
823	677329	557441767	28·68797	9·37130	·0012151
824	678976	559476224	28·70540	9·37510	·0012136
825	680625	561515625	28·72281	9·37889	·0012121
826	682276	563559976	28·74021	9·38267	·0012106
827	683929	565609283	28·75761	9·38646	·0012092
828	685584	567663552	28·77499	9·39024	·0012077
829	687241	569722789	28·79236	9·39402	·0012063
830	**688900**	**571787000**	**28·80972**	**9·39780**	**·0012048**
831	690561	573856191	28·82707	9·40157	.0012034
832	692224	575930368	28·84441	9·40534	·0012019
833	693889	578009537	28·86174	9·40910	·0012005
834	695556	580093704	28·87906	9·41287	·0011990
835	697225	582182875	28·89637	9·41663	·0011976
836	698896	584277056	28·91366	9·42039	·0011962
837	700569	586376253	28·93095	9·42414	·0011947
838	702244	588480472	28·94823	9·42789	·0011933
839	703921	590589719	28·96550	9·43164	·0011919
840	**705600**	**592704000**	**28·98275**	**9·43538**	**·0011905**
841	707281	594823321	29·00000	9·43913	·0011891
842	708964	596947688	29·01724	9·44287	·0011876
843	710649	599077107	29·03446	9·44661	·0011862
844	712336	601211584	29·05168	9·45034	·0011849
845	714025	603351125	29·06888	9·45407	·0011834
846	715716	605495736	29·08608	9·45780	·0011820
847	717409	607645423	29·10326	9·46152	·0011806
848	719104	609800192	29·12044	9·46525	·0011792
849	720801	611960049	29·13760	9·46897	·0011778

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
850	**722500**	**614125000**	**29·15476**	**9·47268**	**·0011765**
851	724201	616295051	29·17190	9·47639	·0011751
852	725904	618470208	29·18904	9·48011	·0011737
853	727609	620650477	29·20616	9·48381	·0011723
854	729316	622835864	29·22328	9·48752	·0011704
855	731025	625026375	29·24038	9·49122	·0011696
856	732736	627222016	29·25748	9·49492	·0011682
857	734449	629422793	29·27456	9·49861	·0011669
858	736164	631628712	29·29164	9·50231	·0011655
859	737881	633839779	29·30870	9·50600	·0011641
860	**739600**	**636056000**	**29·32576**	**9·50968**	**·0011628**
861	741321	638277381	29·34280	9·51337	·0011614
862	743044	640503928	29·35984	9·51705	·0011601
863	744769	642735647	29·37686	9·52073	·0011587
864	746496	644972544	29·39388	9·52441	·0011574
865	748225	647214625	29·41088	9·52808	·0011561
866	749956	649461896	29·42788	9·53175	·0011547
967	751689	651714363	29·44486	9·53542	·0011534
868	753424	653972032	29·46184	9·53908	·0011521
869	755161	656234909	29·47880	9·54274	·0011507
870	**756900**	**658503000**	**29·49576**	**9·54640**	**·0011494**
871	758641	660776311	29·51271	9·55006	·0011481
872	760384	663054848	29·52965	9·55371	·0011468
873	762129	665338617	29·54657	9·55736	·0011455
874	763876	667627624	29·56349	9·56101	·0011442
875	765625	669921875	29·58040	9·56465	·0011428
876	767376	672221376	29·59730	9·56828	·0011415
877	769129	674526133	29·61418	9·57194	·0011402
878	770884	676836152	29·63106	9·57557	·0011389
879	772641	679151439	29·64793	9·57921	·0011376
880	**774400**	**681472000**	**29·66479**	**9·58284**	**·0011364**
881	776161	683797841	29·68164	9·58647	·0011351
882	777924	686128968	29·69848	9·59009	·0011338
883	779689	688465387	29·71531	9·59372	·0011325
884	781456	690807104	29·73214	9·59734	·0011312
885	782225	693154125	29·74895	9·60095	·0011299
886	783996	695506456	29·76575	9·60457	·0011287
887	786769	697864103	29·78254	9·60818	·0011274
888	788544	700227072	29·79933	9·61179	·0011261
889	790321	702595369	29·81610	9·61540	·0011248
890	**792100**	**704969000**	**29·83287**	**9·61900**	**·0011236**
891	793881	707347971	29·84962	9·62260	·0011223
892	795664	709732288	29·86637	9·62620	·0011211
893	797449	712121957	29·88310	9·62980	·0011198
894	799236	714516984	29·89983	9·63339	·0011186
895	801025	716917375	29·91655	9·63698	·0011178
896	802816	719333135	29·93326	9·64057	·0011161
897	804609	721734273	29·94996	9·64415	·0011148
898	806404	724150792	29·96665	9·64774	·0011136
899	808201	726572699	29·98333	9·65131	·0011123

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
900	**810000**	**729000000**	**30·00000**	**9·65489**	**·0011111**
901	811801	731432701	30·01666	9·65847	·0011099
902	813604	733870808	30·03331	9·66204	·0011086
903	815409	736314327	30·04996	9·66561	·0011074
904	817216	738763264	30·06659	9·66918	·0011062
905	819025	741217625	30·08322	9·67274	·0011050
906	820836	743677416	30·09983	9·67630	·0011037
907	822649	746142643	30·11644	9·67986	·0011025
908	824464	748613312	30·13304	9·68342	·0011013
909	826281	751089429	30·14963	9·68697	·0011001
910	**828100**	**753571000**	**30·16621**	**9·69052**	**·0010989**
911	829921	756058031	30·18278	9·69407	·0010977
912	831744	758550825	30·19934	9·6 761	·0010965
913	833569	761048497	30·21589	9·70116	·0010953
914	835396	763551944	30·23243	9·70470	·0010941
915	837225	766060875	30·24897	9·70824	·0010929
916	839056	768575296	30·26549	9·71177	·0010917
917	840889	771095213	30·28201	9·71530	·0010905
918	842724	773620632	30·29851	9·71883	·0010893
919	844561	776151559	30·31501	9·72236	·0010881
920	**846400**	**778688000**	**30·33150**	**9·72589**	**·0010869**
921	848241	781229961	30·34798	9·72941	·0010858
922	850084	783777448	30·36445	9·73293	·0010846
923	851929	786330467	30·38091	9·73645	·0010834
924	853776	788889024	30·39737	9·73996	·0010822
925	855625	791453125	30·41381	9·74347	·0010811
926	857476	794022776	30·43025	9·74698	·0010799
927	859329	796597983	30·44667	9·75049	·0010787
928	861184	799178752	30·46309	9·75400	·0010776
929	863041	801765089	30·47950	9·75750	·0010764
930	**864900**	**804357000**	**30·49590**	**9·76100**	**·0010753**
931	866761	806954491	30·51229	9·76450	·0010741
932	868624	809557568	30·52867	9·76799	·0010730
933	870489	812166237	30·54505	9·77148	·0010718
934	872356	814780504	30·56141	9·77497	·0010707
935	874225	817400375	30·57777	9·77846	·0010695
936	876096	820025856	30·59412	9·78295	·0010684
937	877969	822656953	30·61045	9·78543	·0010672
938	879844	825293672	30·62678	9·78891	·0010661
939	881721	827936019	30·64311	9·79239	·0010650
940	**883600**	**830584000**	**30·65942**	**9·79586**	**·0010638**
941	885481	833237621	30·67572	9·79933	·0010627
942	887364	835896888	30·69202	9·80280	·0010616
943	889249	838561807	30·70830	9·80627	·0010604
944	891136	841232384	30·72458	9·80974	·0010593
945	893025	843908625	30·74085	9·81320	·0010582
946	894916	846590536	30·75711	9·81666	·0010571
947	896808	849278123	30·77336	9·82012	·0010560
948	898704	851971392	30·78961	9·82357	·0010548
949	900601	854670349	30·80584	9·82702	·0010537

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TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
950	**902500**	**857375000**	**30·82207**	**9·83047**	**·0010526**
951	904401	860085351	30·83829	9·83392	·0010515
952	906304	862801408	30·85450	9·83737	·0010504
953	908209	865523177	30·87070	9·84081	·0010493
954	910116	868250664	30·88689	9·84425	·0010482
955	912025	870983875	30·90307	9·84769	·0010471
956	913936	873722816	30·91925	9·85113	·0010460
957	915849	876467493	30·93542	9·85456	·0010449
958	917764	879217912	30·95157	9·85799	·0010438
959	919681	881974079	30·96772	9·86142	·0010427
960	**921600**	**884736000**	**30·98387**	**9·86485**	**·0010417**
961	923521	887503681	31·00000	9·86827	·0010417
962	925444	890277128	31·01612	9·87169	·0010405
963	927369	893056347	31·03224	9·87511	·0010384
964	929296	895841344	31·04835	9·87853	·0010373
965	931225	898632125	31·06445	9·88194	·0010363
966	933156	901428696	31·08054	9·88536	·0010352
967	935089	904231063	31·09662	9·88877	·0010341
968	937024	907039232	31·11270	9·89217	·0010330
969	938961	909853209	31·12876	9·89558	·0010320
970	**940900**	**912673000**	**31·14482**	**9·89898**	**·0010309**
971	942841	915498611	31·16087	9·90238	·0010299
972	944784	918330048	31·17691	9·90578	·0010288
973	946729	921167317	31·19295	9·90918	·0010277
974	948676	924010424	31·20897	9·91257	·0010267
975	950625	926859375	31·22500	9·91596	·0010256
976	952576	929714176	31·24100	9·91935	·0010246
977	954529	932574833	31·25700	9·92273	·0010235
978	956484	935441352	31·27299	9·92612	·0010225
979	958441	938313739	31·28897	9·92950	·0010214
980	**960400**	**941192000**	**31·30495**	**9·93288**	**·0010204**
981	962361	944076141	31·32092	9·93626	·0010192
982	964324	946966168	31·33688	9·93964	·0010183
983	966289	949862087	31·35283	9·94301	·0010173
984	968256	952763904	31·36877	9·94638	·0010163
985	970225	955671625	31·38471	9·94975	·0010152
986	972196	958585256	31·40063	9·95311	·0010142
987	974169	961504803	31·41656	9·95648	·0010132
988	976144	964430272	31·43246	9·95984	·0010121
989	978121	967361669	31·44837	9·96320	·0010111
990	**980100**	**970299000**	**31·46427**	**9·96655**	**·0010101**
991	982081	973242271	31·48015	9·96990	·0010091
992	984064	976191488	31·49603	9·97326	·0010081
993	986049	979146657	31·51190	9·97661	·0010070
994	988036	982107784	31·52776	9·97996	·0010060
995	990025	985074875	31·54362	9·98330	·0010050
996	992016	988047936	31·55947	9·98665	·0010040
997	994009	991026973	31·57531	9·98999	·0010030
998	996004	994011992	31·59114	9·99333	·0010020
999	998001	997002999	31·60696	9·99666	·0010010

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1000	**100000**	**1000000000**	**31·62278**	**10·00000**	**·0010000**
1001	1002001	1003003001	31·63858	10·00332	·00099900
1002	1004004	1006012008	31·65439	10·00666	·00099801
1003	1006009	1009027027	31·67017	10·00999	·00099701
1004	1008016	1012048064	31·68596	10·01331	·00099601
1005	1010025	1015075125	31·70175	10·01664	·00099502
1006	1012036	1018108216	31·71750	10·01996	·00099403
1007	1014049	1021147343	31·73326	10·02328	·00099305
1008	1016064	1024192512	31·74901	10·02659	·00099206
1009	1018081	1027243729	31·76476	10·02991	·00099108
1010	**1020100**	**1030301000**	**31·78050**	**10·03322**	**·00099010**
1011	1022121	1033364331	31·79623	10·03653	·00098912
1012	1024144	1036433728	31·81195	10·03984	·00098814
1013	1026169	1039509197	31·82766	10·04315	·00098717
1014	1028196	1042590744	31·84337	10·04645	·00098619
1015	1030225	1045678375	31·85906	10·04975	·00098522
1016	1032256	1048772096	31·87475	10·05305	·00098425
1017	1034289	1051871913	31·89044	10·05635	·00098328
1018	1036324	1054977832	31·90611	10·05964	·00098232
1019	1038361	1058089859	31·92178	10·06294	·00098135
1020	**1040400**	**1061208000**	**31·93744**	**10·06623**	**·00098039**
1021	1042441	1064332261	31·95309	10·06951	·00097943
1022	1044484	1067462648	31·96873	10·07280	·00097847
1023	1046529	1070599167	31·98437	10·07609	·00097752
1024	1048576	1073741824	32·00000	10·07937	·00097656
1025	1050625	1076890625	32·01562	10·08265	·00097561
1026	1052676	1080045576	32·03123	10·08593	·00097466
1027	1054729	1083206683	32·04684	10·08920	·00097371
1028	1056784	1086373952	32·06244	10·09247	·00097276
1029	1058841	1089547389	32·07803	10·09575	·00097182
1030	**1060900**	**1092727000**	**32·09361**	**10·09902**	**·00097087**
1031	1062961	1095912791	32·10919	10·10228	·00096993
1032	1065024	1099104768	32·12476	10·10555	·00096899
1033	1067089	1102302937	32·14032	10·10881	·00096805
1034	1069156	1105507304	32·15587	10·11207	·00096712
1035	1071225	1108717875	32·17147	10·11533	·00096618
1036	1073296	1111934656	32·18695	10·11859	·00096525
1037	1075369	1115157653	32·20248	10·12184	·00096432
1038	1077444	1118386872	32·21801	10·12510	·00096339
1039	1079521	1121622319	32·23352	10·12834	·00096246
1040	**1081600**	**1124864000**	**32·24903**	**10·13159**	**·00096154**
1041	1083681	1128111921	32·26453	10·13484	·00096061
1042	1085764	1131366088	32·28002	10·13808	·00095969
1043	1087849	1134626507	32·29551	10·14133	·00095877
1044	1089936	1137893184	32·31099	10·14457	·00095785
1045	1092025	1141166125	32·32646	10·14780	·00095694
1046	1094116	1144445336	32·34192	10·15104	·00095602
1047	1096209	1147730823	32·35738	10·15427	·00095511
1048	1098304	1151022592	32·37283	10·15750	·00095420
1049	1100401	1154320649	32·38827	10·16073	·00095329

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1050	**1102500**	**1157625000**	**32·40370**	**10·16396**	**·00095238**
1051	1104601	1160935651	32·41913	10·16779	·00095147
1052	1106704	1164252608	32·43455	10·17041	·00095057
1053	1108809	1167575877	32·44996	10·17363	·00094967
1054	1110916	1170905464	32·46537	10·17685	·00094877
1055	1113125	1174241375	32·48076	10·18007	·00094787
1056	1115136	1177583616	32·49615	10·18329	·00094697
1057	1117249	1180932193	32·51154	10·18650	·00094607
1058	1119364	1184287112	32·52691	10·18971	·00094518
1059	1121481	1187648379	32·54228	10·19292	·00094429
1060	**1123600**	**1191016000**	**32·55764**	**10.19613**	**·00094340**
1061	1125721	1194389981	32·57299	10·19933	·00094250
1062	1127844	1197770328	32·58834	10·20254	·00094162
1063	1129969	1201157047	32·60358	10·20574	·00094073
1064	1132096	1204550144	32·61901	10·20894	·00093985
1065	1134225	1207949625	32·63434	10·21213	·00093897
1066	1136356	1211355496	32·64965	10·21533	·00093809
1067	1138489	1214767763	32·66496	10·21852	·00093721
1068	1140624	1218186432	32·68027	10·22171	·00093633
1069	1142761	1221611509	32·69556	10·22490	·00093545
1070	**1144900**	**1225043000**	**32·71085**	**10·22809**	**·00093458**
1071	1147041	1228480911	32·72614	10·23128	·00093371
1072	1149184	1231925248	32·74141	10·23446	·00093283
1073	1151329	1235376017	32·75668	10·23764	·00093197
1074	1153476	1238833224	32·77194	10·24082	·00093110
1075	1155625	1242296875	32·78719	10·24400	·00093023
1076	1157776	1245766976	32·80244	10·24717	·00092937
1077	1159929	1249243533	32·81768	10·25035	·00092850
1078	1162084	1252726552	32·83291	10·25352	·00092764
1079	1164241	1256216039	32·84813	10·25669	·00092678
1080	**1166400**	**1259712000**	**32·86335**	**10·25985**	**·00092592**
1081	1168561	1263214441	32·87856	10·26302	·00092507
1082	1170724	1266723368	32·89377	10·26618	·00092421
1083	1172889	1270238787	32·90896	10·26935	·00092336
1084	1175056	1273760704	32·92415	10·27251	·00092251
1085	1177225	1277289125	32·93934	10·27566	·00092166
1086	1179396	1280824056	32·95451	10·27882	·00092081
1087	1181569	1284365503	32·96968	10·28197	·00091996
1088	1183744	1287913472	32·98484	10·28513	·00091912
1089	1185921	1291467969	33·00000	10·28828	·00091827
1090	**1188100**	**1295029000**	**33·01515**	**10·29142**	**·00091743**
1091	1190281	1298596571	33·03027	10·29457	·00091659
1092	1192464	1302170688	33·04542	10·29771	·00091575
1093	1194649	1305751357	33·06055	10·30086	·00091491
1094	1196836	1309338584	33·07567	10·30400	·00091408
1095	1199025	1312932375	33·09078	10·30714	·00091324
1096	1201216	1316532736	33·10589	10·31027	·00091240
1097	1203409	1320139673	33·12099	10·31341	·00091158
1098	1205604	1323753192	33·13608	10·31654	·00091075
1099	1207801	1327373299	33·15117	10·31967	·00090992

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1100	**1210000**	**1331000000**	**33·16625**	**10·32280**	**·00090909**
1101	1212201	1334633301	33·18132	10·32593	·00090826
1102	1214404	1338273208	33·19638	10·32905	·00090744
1103	1216609	1341919727	33·21144	10·33218	·00090662
1104	1218816	1345572864	33·22669	10·33530	·00090580
1105	1221025	1349232625	33·24154	10·33842	·00090498
1106	1223236	1352899016	33·25658	10·34153	·00090416
1107	1225449	1356572043	33·27161	10·34465	·00090334
1108	1227664	1360251712	33·28663	10·34776	·00090253
1109	1229881	1363938029	33·30165	10·35088	·00090171
1110	**1232100**	**1367631000**	**33·31666**	**10·35399**	**·00090090**
1111	1234321	1371330631	33·33167	10·35710	·00090009
1112	1236544	1375036928	33·34666	10·36020	·00089928
1113	1238769	1378749897	33·36165	10·36331	·00089847
1114	1240996	1382469544	33·37664	10·36641	·00089767
1115	1243225	1386195875	33·39161	10·36951	·00089686
1116	1245456	1389928896	33·40659	10·37261	·00089607
1117	1247689	1393668613	33·42155	10·37571	·00089525
1118	1249924	1397415032	33·43651	10·37880	·00089445
1119	1252161	1401168159	33·45146	10·38190	·00089365
1120	**1254400**	**1404928000**	**33·46640**	**10·38499**	**·00089286**
1121	1256641	1408694561	33·48134	10·38808	·00089206
1122	1258884	1412467848	33·49627	10·39117	·00089127
1123	1251129	1416247867	33·51120	10·39425	·00089047
1124	1263376	1420034624	33·52611	10·39734	·00088968
1125	1265625	1423828125	33·54102	10·40042	·00088889
1126	1267876	1427628376	33·55592	10·40350	·00088810
1127	1270129	1431435383	33·57082	10·40658	·00088731
1128	1272384	1435249152	33·58571	10·40966	·00088652
1129	1274641	1439069689	33·60060	10·41273	·00088574
1130	**1276900**	**1442897000**	**33·61547**	**10·41580**	**·00088496**
1131	1279161	1446731091	33·63034	10·41888	·00088417
1132	1281424	1450571968	33·64521	10·42195	·00088339
1133	1283689	1454419637	33·66007	10·42501	·00088261
1134	1285956	1458274104	33·67492	10·42808	·00088183
1135	1288225	1462135375	33·68976	10·43114	·00088106
1136	1290496	1466003456	33·70460	10·43421	·00088028
1137	1292769	1469878353	33·71743	10·43727	·00087951
1138	1295044	1473760072	33·73406	10·44037	·00087873
1139	1297321	1477648619	33·74907	10·44338	·00087796
1140	**1299600**	**1481544000**	**33·76389**	**10·44644**	**·00087719**
1141	1301881	1485446221	33·77869	10·44949	·00087642
1142	1304164	1489355288	33·79349	10·45254	·00087566
1143	1306449	1493271207	33·80828	10·45559	·00087489
1144	1308736	1497193984	33·82307	10·45864	·00087413
1145	1311025	1501123625	33·83785	10·46169	·00087336
1146	1313316	1505060136	33·85262	10·46473	·00087260
1147	1315609	1509003523	33·86739	10·46778	·00087184
1148	1317904	1512953792	33·88215	10·47082	·00087108
1149	1320201	1516910949	33·89690	10·47386	·00087032

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1150	**1322500**	**1520875000**	**33·91165**	**10·47690**	**00086957**
1151	1324801	1524845951	33·92639	10·47993	·00086881
1152	1327104	1528823808	33·94113	10·48297	·00086806
1153	1329409	1532808577	33·95585	10·48600	·00086730
1154	1331716	1536800264	33·97058	10·48903	·00086655
1155	1334025	1540798875	33·98529	10·49206	·00086580
1156	1336336	1544804416	34·00000	10·49508	·00086505
1157	1338649	1548816893	34·01470	10·49811	·00086430
1158	1340964	1552836312	34·02940	10·50113	·00086356
1159	1343281	1556862679	34·04409	10·50416	·00086281
1160	**1345600**	**1560896000**	**34·05877**	**10-50718**	**·00086207**
1161	1347921	1564936281	34·07345	10·51019	·00086132
1162	1350244	1568983528	34·08812	10·51321	·00086059
1163	1352569	1573037749	34·10279	10·51623	·00085985
1164	1354896	1577098944	34·11744	10·51924	·00085911
1165	1357225	1581167125	34·13210	10·52225	·00085837
1166	1359556	1585242296	34·14674	10·52526	·00085763
1167	1361889	1589324463	34·16138	10·52827	·00085690
1168	1364224	1593413632	34·17601	10·53127	·00085616
1169	1366561	1597509809	34·19064	10·53428	·00085543
1170	**1368900**	**1601613000**	**34·20526**	**10·53728**	**·00085470**
1171	1371241	1605723211	34·21988	10·54028	00085397
1172	1373584	1609840448	34·23449	10·54328	·00085324
1173	1375929	1613964717	34·24909	10·54928	·00085251
1174	1378276	1618096024	34·26368	10·55928	·00085179
1175	1380625	1622234375	34·27827	10·55227	·00085106
1176	1382976	1626379776	34·29286	10·55526	·00085034
1177	1385329	1630532233	34·30743	10·55826	·00084962
1178	1387684	1634691752	34.32200	10·56124	·00084890
1179	1390041	1638858339	34·33657	10·56423	·00084818
1180	**1392400**	**1643032000**	**34·35113**	**10·56722**	**·00084716**
1181	1394761	1647212741	34·36568	10·57020	·00084674
1182	1397124	1651400568	34·38023	10·57318	·00084602
1183	1399489	1655595487	34·39477	10·57617	·00084531
1184	1401856	1659797504	34·40930	10·57914	·00084459
1185	1404225	1664006625	34·42383	10·58212	·00084388
1186	1406596	1668222856	34·43835	10·58510	·00084317
1187	1408969	1672446203	34·45287	10·58807	·00084246
1188	1411344	1676676672	34·46738	10·59104	·00084175
1189	1413721	1680914629	34·48188	10·59402	·00084104
1190	**1416100**	**1685159000**	**34·49638**	**10·59698**	**·00084034**
1191	1418481	1689410871	34·51087	10·59995	·00083963
1192	1420864	1693669888	34·52535	10·60292	·00083893
1193	1423249	1697936057	34·53983	10·60588	·00083823
1194	1425636	1702209384	34·55431	10·60885	·00083752
1195	1428025	1706489875	34·56877	10·61181	00083682
1196	1430416	1710777536	34·58323	10·61477	·00083612
1197	1432809	1715072373	34·59769	10·61772	·00083542
1198	1435204	1719374392	34·61214	10·62068	·00083472
1199	1437601	1723683599	34·62658	10·62363	·00083403

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots	Cube Roots.	Reciprocals.
1200	**1440000**	**1728000000**	**34·64102**	**10·62659**	**·00083333**
1201	1442401	1732323601	34·65545	10·62954	·00083264
1202	1444804	1736654408	34·66987	10·63249	·00083195
1202	1447209	1740992427	34·68429	10·63543	·00083126
1204	1449616	1745337664	34·69870	10·63838	·00083056
1205	1452025	1749690125	34·71311	10·64132	·00082988
1206	1454436	1754049816	34·72751	10·64427	·00082919
1207	1456849	1758416743	34·74191	10·64721	·00082850
1208	1459264	1762790912	34·75629	10·65015	·00082781
1209	1461681	1767172329	34·77068	10·65309	·00082713
1210	**1464100**	**1771561000**	**34·78505**	**10·65602**	**·00082645**
1211	1466521	1775956931	34·79943	10·65896	·00082576
1212	1468944	1780360128	34·81379	10·66189	·00082508
1213	1471369	1784770597	34·82815	10·66482	·00082440
1214	1473796	1789188344	34·84250	10·66775	·00082372
1215	1476225	1793613375	34·85685	10·67068	·00082305
1216	1478656	1798045696	34·87119	10·67361	·00082237
1217	1481089	1802485313	34·88553	10·67653	·00082169
1218	1483524	1806932232	34·89986	10·67946	·00082102
1219	1485961	1811386459	34·91418	10·68238	·00082034
1220	**1488400**	**1815848000**	**34·92850**	**10·68530**	**·00081967**
1221	1490841	1820316861	34·94281	10·68822	·00081900
1222	1493284	1824793048	34·95712	10·69113	·00081833
1223	1495729	1829276567	34·97142	10·69405	·00081766
1224	1498176	1833764247	34·98571	10·69696	·00081699
1225	1500625	1838265625	35·00000	10·69987	·00081633
1226	1503276	1842771176	35·01428	10·70279	·00081566
1227	1505529	1847284083	35·02856	10·70569	00081500
1228	1507984	1851804352	35·04283	10·70860	·00081433
1229	1510441	1856331989	35·05710	10·71151	·00081367
1230	**1512900**	**1860867000**	**35·07136**	**10·71441**	**·00081301**
1231	1515361	1865409391	35·08561	10·71732	·00081235
1232	1517824	1869959168	35·09986	10·72022	·00081169
1233	1520289	1874516337	35·11410	10·72312	·00081103
1234	1522756	1879080904	35·12834	10·72601	·00081037
1235	1525225	1883652875	35·14256	10·72891	·00080971
1236	1527696	1888232256	35·15679	10·73181	·00080906
1237	1530169	1892819053	35·17101	10·73470	·00080841
1238	1532644	1897413272	35·18522	10·73759	·00080775
1239	1535121	1902014919	35·19943	10·74048	·00080710
1240	**1537600**	**1906624000**	**35·21363**	**10·74337**	**·00080645**
1241	1540081	1911240521	35·22783	10·74626	·00080580
1242	1542564	1915864488	35·24202	10·74914	·00080515
1243	1545049	1920495907	35·25621	10·75203	·00080451
1244	1547536	1925134784	35·27038	10·75491	·00080386
1245	1550025	1929781125	35·28456	10·75779	·00080321
1246	1552521	1934434936	35·29873	10·76067	·00080257
1247	1555009	1939096223	35·31289	10·76355	·00080192
1248	1557504	1943764992	35·32704	10·76643	·00080128
1249	1560001	1948441249	35·34119	10·76930	00080064

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1250	**1562500**	**1953125000**	**35·35534**	**10·77217**	**·00080000**
1251	1565001	1957816251	35·36948	10·77505	·00079936
1252	1567504	1962515008	35·38361	10·77792	·00079872
1253	1570009	1967221277	35·39774	10·78078	·00079808
1254	1572516	1971935064	35·41186	10·78365	·00079745
1255	1575025	1976656375	35·42598	10·78652	·00079681
1256	1577536	1981385216	35·44009	10·78938	·00079618
1257	1580049	1986121593	35·45420	10·79224	·00079554
1258	1582564	1990865512	35·46830	10·79511	·00079491
1259	1585081	1995616979	35·48239	10·79796	·00079428
1260	**1587600**	**2000376000**	**35·49648**	**10·80082**	**·00079365**
1261	1590121	2005142581	35·51056	10·80368	·00079302
1262	1592644	2009916728	35·52464	10·80653	·00079239
1263	1595166	2014698447	35·53871	10·80939	·00079177
1264	1697696	2019487744	35·55278	10·81224	·00079114
1265	1600225	2024284625	35·56684	10·81509	·00079051
1266	1602756	2029089096	35·58089	10·81794	·00078989
1267	1605289	2033901163	35·59494	10·82079	.00078927
1268	1607824	2038720832	35·60899	10·82363	·00078864
1269	1610361	2043548109	35·62303	10·82648	·00078802
1270	**1612900**	**2048383000**	**35·63706**	**10·82932**	**·00078740**
1271	1615441	2053225511	35·65109	10·83216	·00078678
1272	1617984	2058075648	35·66511	10·83500	·00078616
1273	1620529	2062933417	35·67910	10·83784	·00078555
1274	1623076	2067798824	35·69314	10·84069	·00078493
1275	1625625	2072671875	35·70714	10·84351	·00078431
1276	1628176	2077552576	35·72114	10·84635	·00078370
1277	1630729	2082440933	35·73514	10·84918	·00078309
1278	1633284	2087336952	35·74913	10·85201	·00078247
1279	1635841	2092240639	35·76311	10·85484	·00078186
1280	**1638400**	**2097152000**	**35·77709**	**10·85767**	**·00078125**
1281	1640961	2102071841	35·79106	10·86050	·00078064
1282	1643524	2106997768	35·80503	10·86332	·00078003
1283	1646089	2111932187	35·81899	10·86615	·00077942
1284	1648656	2116874304	35·83295	10·86897	·00077882
1285	1651225	2121824125	35·84690	10·87179	·00077821
1286	1653796	2126781656	35·86084	10·87461	·00077760
1287	1656369	2131746903	35·87478	10·87743	·00077700
1288	1658944	2136719872	35·88872	10·88024	·00077640
1289	1661521	2141700569	35·90265	10·88306	·00077580
1290	**1664100**	**2146689000**	**35·91657**	**10·88587**	**·00077519**
1291	1666681	2151685171	35·93049	10·88868	·00077459
1292	1669264	2156689088	35·94440	10·89150	·00077399
1293	1671849	2161700757	35·95831	10·89430	·00077340
1294	1674436	2166720184	35·97221	10·89711	·00077280
1295	1677025	2171747375	35·98611	10·89992	·00077220
1296	1679616	2176782336	36·00000	10·90272	·00077160
1297	1682209	2181825073	36·01389	10·90553	·00077101
1298	1684804	2186875592	36·02777	10·90833	·00077042
1299	1687401	2191933899	36·04164	10·91113	·00076982

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1300	**1690000**	**2197000000**	**36·05551**	**10·91393**	**·00076923**
1301	1692601	2202073901	36·06938	10·91673	·00076864
1302	1695204	2207155608	36·08324	10·91952	·00076805
1303	1697809	2212245127	36·09709	10·92232	·00076746
1304	1700416	2217324464	36·11094	10·92511	·00076687
1305	1703025	2222447625	36·12478	10·92790	·00076628
1306	1705636	2227560616	36·13862	10·93069	·00076570
1307	1708249	2232681443	36·15246	10·93348	·00076511
1308	1710864	2237810112	36·16628	10·93627	·00076453
1309	1713481	2242946629	36·18010	10·93906	·00076394
1310	**1716100**	**2248091000**	**36·19392**	**10·94184**	**·00076336**
1311	1718721	2253243231	36·20773	10·94463	·00076278
1312	1721344	2258403328	36·22154	10·94751	·00076220
1313	1723969	2263571297	36·23534	10·95019	·00076164
1314	1726596	2268747144	36·24914	10·95297	·00076104
1315	1729225	2273930875	36·26263	10·95575	·00076046
1316	1731856	2279122496	36·27671	10·95852	·00075988
1317	1734489	2284322013	36·29042	10·96130	·00075930
1318	1737124	2289529432	36·30427	10·96407	·00075873
1319	1739761	2294744759	36·31804	10·96684	·00075815
1320	**1742400**	**2299968000**	**36·33180**	**10·96961**	**·00075758**
1321	1745041	2305199161	36·34556	10·97238	·00075700
1322	1747684	2310438248	36·35932	10·97515	·00075643
1323	1750329	2315685267	36·37307	10·97792	·00075586
1324	1752976	2320940224	36·38681	10·98068	·00075529
1325	1755625	2326203125	36·40055	10·98345	·00075472
1326	1758276	2331473976	36·41428	10·98621	·00075415
1327	1760929	2336752783	36·42801	10·98897	·00075358
1328	1763584	2342039552	36·44173	10·99173	·00075301
1329	1766241	2347334289	36·45545	10·99449	·00075245
1330	**1768900**	**2352637000**	**36·46916**	**10·99724**	**·00075188**
1331	1771561	2357947691	36·48287	11·00000	·00075131
1332	1774224	2363266368	36·49658	11·00275	·00075075
1333	1776889	2368593037	36·51027	11·00551	·00075019
1334	1779556	2373927704	36·52396	11·00826	·00074963
1335	1782225	2379270375	36·53765	11·01101	·00074906
1336	1784896	2384621056	36·55134	11·01376	·00074850
1337	1787569	2389979753	36·56501	11·01650	·00074794
1338	1790244	2395346472	36·57868	11·01925	·00074738
1339	1792921	2400721219	36·59235	11·02199	·00074683
1340	**1795600**	**2406104000**	**36·60601**	**11·02474**	**·00074627**
1341	1798281	2411494821	36·61967	11·02748	·00074571
1342	1800964	2416893688	36·63332	11·03022	·00074516
1343	1803649	2422300607	36·64691	11·03296	·00074460
1344	1806336	2427715584	36·66061	11·03570	·00074405
1345	1809025	2433138625	36·67424	11·03843	·00074349
1346	1811716	2438569736	36·68787	11·04117	·00074294
1347	1814409	2444008923	36·70150	11·04390	·00074239
1348	1817104	2449456192	36·71512	11·04663	·00074184
1349	1819801	2454911549	36·72874	11·04936	·00074129

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1350	**1822500**	**2460375000**	**36·74235**	**11·05209**	**·00074074**
1351	1825201	2465846551	36·75595	11·05482	·00074019
1352	1827904	2471326208	36·76955	11·05755	·00073964
1353	1830609	2476813977	36·78315	11·06028	·00073910
1354	1833316	2482309864	36·79674	11·06300	·00073855
1355	1836025	2487813875	36·81032	11·06572	·00073801
1356	1838736	2493326016	36·82391	11·06844	·00073746
1357	1841449	2498846293	36·83748	11·07116	·00073692
1358	1844164	2504374712	36·85105	11·07388	·00073638
1359	1846881	2509911279	36·86462	11·07660	·00073584
1360	**1849600**	**2515456000**	**36·87818**	**11·07932**	**·00073529**
1361	1852321	2521008881	36·89173	11·08203	·00073475
1362	1855044	2526569928	36·90528	11·08474	·00073421
1363	1857769	2532139147	36·91883	11·08746	·00073368
1364	1860496	2537716544	36·93237	11·09017	·00073314
1365	1863225	2543302125	36·94591	11·09288	·00073260
1366	1865956	2548895896	36·95944	11·09559	·00073206
1367	1868689	2554497863	36·97296	11·09829	·00073153
1368	1871424	2560108032	36·98648	11·10100	·00073099
1369	1874161	2565726409	36·00000	11·10370	·00073046
1370	**1876900**	**2571353000**	**36·01351**	**11·10641**	**·00072993**
1371	1879641	2576987811	37·02702	11·10911	·00072939
1372	1882384	2582630848	37·04052	11·11181	·00072886
1373	1885129	2588282117	37·05401	11·11451	·00072833
1374	1887876	2593941624	37·06751	11·11720	·00072780
1375	1890625	2599609375	37·08999	11·11990	·00072727
1376	1893376	2605285376	37·09447	11·12260	·00072674
1377	1896129	2610969633	37·10795	11·12529	·00072622
1378	1898884	2616662152	37·12142	11·12798	·00072569
1379	1901641	2622362939	37·13489	11·13067	·00072516
1380	**1904400**	**2628072000**	**37·14835**	**11·13336**	**·00072464**
1381	1907161	2633789341	37·16181	11·13605	·00072411
1382	1909924	2639514968	37·17526	11·13874	·00072359
1383	1912689	2645248887	37·18871	11·14142	·00072307
1384	1915456	2650991104	37·20215	11·14411	·00072254
1385	1918225	2656741625	37·21559	11·14679	·00072202
1386	1920996	2662500456	37·22902	11·14947	·00072150
1387	1923769	2668267603	37·24245	11·15216	·00072098
1388	1926544	2674043072	37·25587	11·15483	·00072046
1389	1929321	2679826869	37·26929	11·15751	·00071994
1390	**1932100**	**2685619000**	**37·28270**	**11·16019**	**·00071942**
1391	1934881	2691419471	37·29611	11·16287	·00071891
1392	1937664	2697228288	37·30952	11·16554	·00071839
1393	1940449	2703045457	37·32292	11·16821	·00071788
1394	1943236	2708870984	37·33631	11·17089	·00071736
1395	1946025	2714704875	37·34970	11·17356	·00071685
1396	1948816	2720547136	37·36308	11·17622	·00071633
1397	1951609	2726397773	37·37646	11·17889	·00071582
1398	1954404	2732256792	37·38984	11·18156	·00071531
1399	1957201	2738124199	37·40321	11·18423	·00071480

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1400	**1960000**	**2744000000**	**37·41657**	**11·18689**	**·00071429**
1401	1962801	2749884201	37·42993	11·18955	·00071378
1402	1965604	2755776808	37·44329	11·19221	·00071327
1403	1968409	2761677827	37·45664	11·19487	·00071276
1404	1971216	2767587264	37·46999	11·19753	·00071225
1405	1974025	2773505123	37·48333	11·20019	·00071174
1406	1976836	2779431416	37·49667	11·20285	·00071124
1407	1979649	2785366143	37·51000	11·20550	·00071073
1408	1982464	2791309312	37·52333	11·20816	·00071023
1409	1985281	2797260929	37·53665	11·21081	·00070972
1410	**1988100**	**2803221000**	**37·54997**	**11·21346**	**·00070922**
1411	1990921	2809189531	37·56328	11·21611	·00070872
1412	1993744	2815166528	37·57659	11·21876	·00070822
1413	1996569	2821151997	37·58989	11·22141	·00070771
1414	1999396	2827145944	37·60319	11·22401	·00070721
1415	2002225	2833148375	37·61649	11·22670	·00070671
1416	2005056	2839159296	37 62978	11·22934	·00070621
1417	2007889	2845178713	37·64306	11·23199	·00070572
1418	2010724	2851206632	37·65634	11·23463	·00070522
1419	2013561	2857243059	37·66962	11·23727	·00070472
1420	**2016400**	**2863288000**	**37·68289**	**11·23991**	**·00070423**
1421	2019241	2869341461	37·69615	11·24255	·00070373
1422	2022084	2875403448	37·70942	11·24518	·00070323
1423	2024929	2881473967	37·72267	11·24782	·00070274
1424	2027776	2887553024	37·73592	11·25045	·00070225
1425	2030625	2893640625	37·74917	11 25309	·00070175
1426	2033476	2899736776	37·76242	11·25572	·00070126
1427	2036329	2905841483	37·77565	11·25835	·00070077
1428	2039184	2911954752	37·78889	11·26098	·00070028
1429	2042041	2918076589	37·80212	11·26360	·00069979
1430	**2044900**	**2924207000**	**37·81534**	**11·26623**	**·00069930**
1431	2047761	2930345991	37·82856	11·26886	·00069881
1432	2050624	2936493568	37·84178	11·27148	·00069832
1433	2053489	2942649737	37·85499	11·27410	·00069784
1434	2056356	2948814504	37·86819	11·27673	·00069735
1435	2059225	2954987875	37·88139	11·27935	·00069686
1436	2062096	2961169856	37·89459	11·28197	·00069638
1437	2064969	2967360453	37·90778	11·28458	·00069589
1438	2067844	2973559672	37·92097	11·28720	·00069541
1439	2070721	2979767519	37·93415	11·28982	·00069493
1440	**2073600**	**2985984000**	**37·94733**	**11·29243**	**00069444**
1441	2076481	2992209121	37·96051	11·29505	·00069396
1442	2079364	3098442888	37·97368	11·29766	·00069348
1443	2082249	3004685307	37·98684	11·30027	·00069300
1444	2085136	3010936384	38·00000	11·30288	·00069252
1445	2088025	3017196125	38·01316	11·30549	·00069204
1446	2080916	3023464536	38·02631	11·30809	·00069156
1447	2093809	3029741623	38·03945	11·31070	·00069108
1448	2096704	3036027392	38·05260	11·31331	·00069061
1449	2099601	3042321849	38·06573	11·31591	·00069013

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1450	**2102500**	**3048625000**	**38·07887**	**11·31851**	**·00068966**
1451	2105401	3054936851	38·09199	11·32111	·00068918
1452	2108304	3061257408	38·10512	11·32371	·00068871
1453	2111209	3067586777	38·11824	11·32631	00068823
1454	2114116	3073924664	38·13135	11·32891	00068776
1455	2117025	3080271375	38·14446	11·33151	·00068729
1456	2119936	3086626816	38·15757	11·33410	·00068681
1457	2122849	3092990993	38·17067	11·33670	·00068634
1458	2125764	3099363912	38·18377	11·33929	00068587
1459	2128681	3105745579	38·19686	11·34188	·00068540
1460	**2131600**	**3112136000**	**38·20995**	**11·34447**	**·00068493**
1461	2134521	3118535181	38·22303	11·34706	·00068446
1462	2137444	3124943128	38·23611	11·34965	·00068399
1463	2140369	3131359847	38·24918	11·35224	·00068353
1464	2143296	3137785344	38·26225	11·35482	·00068306
1465	2146225	3144219625	38·27532	11·35741	·00068259
1466	2149156	3150662696	38·28838	11·35999	·00068213
1467	2152089	3157114563	38·30144	11·36257	·00068166
1468	2155024	3163575232	38·31449	11·36515	·00068120
1469	2157961	3170044709	38·32754	11·36773	·00068074
1470	**2160900**	**3176523000**	**38·34058**	**11·37031**	**·00068027**
1471	2163841	3183010111	38·35362	11·37289	·00067981
1472	2166784	3189506048	38·36665	11·37547	·00067935
1473	2169729	3196010817	38·37968	11·37804	·00067889
1474	2172676	3202524424	38·39271	11·38062	·00067843
1475	2175625	3209046875	38·40573	11·38319	·00067797
1476	2178576	3215578176	38·41875	11·38576	00067751
1477	2181529	3222118333	38·43176	11·38833	00067705
1478	2184484	3228667352	38·44477	11·39090	00067659
1479	2187441	3235225239	38·45777	11·39347	·00067613
1480	**2190400**	**3241792000**	**38·47077**	**11·39604**	**·00067568**
1481	2193361	3248367641	38·48376	11·39860	·00067522
1482	2196324	3254952168	38·49675	11·40117	·00067476
1483	2199289	3261545587	38·50974	11·40373	·00067431
1484	2202256	3268147904	38·52272	11·40630	·00067385
1485	2205225	3274759125	38·53570	11·40886	·00067340
1486	2208196	3281379256	38·54867	11·41142	·00067295
1487	2211169	3288008303	38·56164	11·41398	·00097249
1488	2214144	3294646272	38·57460	11·41653	·00067204
1489	2217121	3301293169	38·58756	11·41909	·00067159
1490	**2220100**	**3307949000**	**38·60052**	**11·42165**	**·00067114**
1491	2223081	3314613771	38·61347	11·42420	·00067069
1492	2226004	3321287488	38·62642	11·42676	·00067024
1493	2229049	3327970157	38·63936	11·42931	·00066979
1494	2232036	3334661784	38·65230	11·43186	·00066934
1495	2235025	3341362375	38·66523	11·43441	·00066890
1496	2238016	3348071936	38·67816	11·43696	·00066845
1497	2241009	3354790473	38·69108	11·43951	·00066800
1498	2244004	3361517992	38·70400	11·44205	·00066756
1499	2247001	3368254499	38·71692	11·44460	·00066711

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1500	**2250000**	**3375000000**	**38·72983**	**11·44714**	**·00066667**
1501	2253001	3381754501	38·74274	11·44969	·00066622
1502	2256004	3388518008	38·75564	11·45223	·00066578
1503	2259009	3395290527	38·76854	11·45477	·00066534
1504	2262016	3402072064	38·78144	11·45731	·00066489
1505	2265025	3408862625	38·79433	11·45985	·00066445
1506	2268036	3415662216	38·80722	11·46238	·00066401
1507	2271049	3422470843	38·82010	11·46492	·00066357
1508	2274064	3429288512	38·83298	11·46746	·00066313
1509	2277081	3436115229	38·84585	11·46999	·00066269
1510	**2280100**	**3442951000**	**38·85872**	**11·47252**	**·00066225**
1511	2283121	3449795831	38·87158	11·47506	·00066181
1512	2286144	3456649728	38·88444	11·47759	·00066138
1513	2289169	3463512697	38·89730	11·48012	·00066094
1514	2292196	3470384744	38·91015	11·48265	·00066050
1515	2295225	3477265875	38·92300	11·48517	·00066007
1516	2298256	3484156096	38·93584	11·48770	·00065963
1517	2301289	3491055413	38·94868	11·49022	·00065920
1518	2304324	3597963832	38·96152	11·49275	·00065876
1519	2307361	3504881359	38·97435	11·49527	·00065833
1520	**2310400**	**3511808000**	**38·98718**	**11·49779**	**·00065789**
1521	2313441	3518743761	39·00000	11·50032	·00065746
1522	2316484	3525688648	39·01282	11·50283	·00065703
1523	2319529	3532642667	39·02563	11·50535	·00065660
1524	2322576	3539605824	39·03844	11·50787	·00065617
1525	2325625	3546578125	39·05125	11·51039	·00065574
1526	2328676	3553559576	39·06405	11·51290	·00065531
1527	2331729	3560549552	39·07685	11·51542	·00065488
1528	2334784	3567558183	39·08964	11·51793	·00065445
1529	2337841	3574558889	39·10243	11·52044	·00065402
1530	**2340900**	**3581577000**	**39·11521**	**11·52295**	**·00065359**
1531	2343961	3588604291	39·12800	11·52546	·00065317
1532	2347024	3595640768	39·14077	11·52797	·00065274
1533	2350089	3602686437	39·15354	11·53048	·00065232
1534	2353156	3609741304	39·16631	11·53299	00065189
1535	2356225	3616805375	39·17908	11·53549	·00065147
1536	2359256	3623878656	39·19184	11·53800	·00065104
1537	2362369	3630961153	39·20459	11·54050	·00065062
1538	2365444	3638052872	39·21734	11·54300	·00065020
1539	2368521	3645153819	39·23009	11·54550	·00064977
1540	**2371600**	**3652264000**	**39·24283**	**11·54800**	**·00064935**
1541	2374681	3659383421	39·25557	11·55050	·00064893
1542	2377764	3666512088	39·26831	11·55300	·00064851
1543	2380849	3673650007	39·28104	11·55550	·00064809
1544	2383936	3680797184	39·29377	11·55799	·00064767
1545	2387025	3687953625	39·30649	11·56049	·00064725
1546	2390116	3695119336	39·31921	11·56298	·00064683
1547	2393209	3702294323	39·33192	11·56547	·00064641
1548	2396304	3709478592	39·34463	11·56797	·00064599
1549	2399401	3716672149	39·35734	11·57046	00064558

TABLE OF SQUARES, CUBES, AND SQUARE AND CUBE ROOTS—*continued.*

Num.	Squares.	Cubes.	Square Roots.	Cube Roots.	Reciprocals.
1550	**2402500**	**3723875000**	**39·37004**	**11·57295**	**·00064516**
1551	2405601	3731087151	39·38274	11·57543	·00064475
1552	2408704	3738308608	39·39543	11·57792	·00064433
1553	2411809	3745539377	39·40812	11·58041	·00064391
1554	2414916	3752779464	39·42081	11·58289	·00064350
1555	2418025	3760028875	39·43349	11·58538	·00064309
1556	2421136	3767287616	39·44617	11·58786	·00064267
1557	2424249	3774555693	39·45884	11·59034	·00064226
1558	2427364	3781833112	39·47151	11·59282	·00064185
1559	2430481	3789119879	39·48417	11·59530	·00064144
1560	**2433600**	**3796416000**	**39·49684**	**11·59778**	**·00064103**
1561	2436721	3803721481	39·50949	11·60026	·00064061
1562	2439844	3811036328	39·52215	11·60273	·00064020
1563	2442969	3818360547	39·53479	11·60521	·00063980
1564	2446096	3825641444	39·54744	11·60768	·00063939
1565	2449225	3833037125	39·56008	11·61016	·00063898
1566	2452356	3840389496	39·57272	11·61263	·00063857
1567	2455489	3847751263	39·58535	11·61510	·00063816
1568	2458624	3855123432	39·59798	11·61757	·00063776
1569	2461761	3862503009	39·61060	11·62004	·00063735
1570	**2464900**	**3869883000**	**39·62326**	**11·62251**	**·00063694**
1571	2468041	3877292411	39·63584	11·62498	·00063654
1572	2471184	3884701248	39·64846	11·62744	·00063613
1573	2474329	3892119157	39·66106	11·62991	·00063573
1574	2477476	3899547224	39·67367	11·63237	·00063532
1575	2480625	3906984375	39·68627	11·63483	·00063492
1576	2483776	3914430976	39·69887	11·63730	·00063452
1577	2486929	3921887033	39·71146	11·63976	·00063412
1578	2490084	3929352552	39·72405	11·64222	·00063371
1579	2493241	3936827539	39·73663	11·64468	·00063331
1580	**2496400**	**3944312000**	**39·74921**	**11·64713**	**·00063291**
1581	2499561	3951805941	39·76179	11·64959	·00063251
1582	2502724	3959309368	39·77436	11·65205	·00063211
1583	2505889	3966822287	39·78693	11·65450	·00063171
1584	2509056	3974344704	39·79950	11·65695	·00063131
1585	2512225	3981876625	39·81206	11·65941	·00063091
1586	2515396	3989418056	39·82462	11·66186	·00063052
1587	2518569	3996969003	39·83717	11·66431	·00063012
1588	2521744	4004529472	39·84972	11·66676	·00062972
1589	2524921	4012099469	39·86226	11·66921	·00062933
1590	**2528100**	**4019679000**	**39·87480**	**11·67165**	**·00062893**
1591	2531281	4027268071	39·88734	11·67410	·00062854
1592	2534464	4034866688	39·89987	11·67654	·00062814
1593	2537649	4042474857	39·91240	11·67899	·00062775
1594	2540836	4050092584	39·92493	11·68143	·00062735
1595	2544025	4057719875	39·93745	11·68387	·00062696
1596	2547216	4065356736	39·94997	11·68632	·00062657
1597	2550409	4073003173	39·96248	11·68876	·00062617
1598	2553604	4080659192	39·97499	11·69120	·00062578
1599	2556801	4088324799	39·98750	11·69363	·00062539
1600	**2560000**	**4096000000**	**40·00000**	**11·69607**	**·00062500**

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